

ABEM

Instruction Manual



Terrameter SAS 1000 / 4000

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WARNING!

The ABEM Terrameter SAS 1000 / 4000 delivers high voltages and currents. Always consider all cables and electrodes connected directly or indirectly to the Terrameter to carry current.

Stay away from cables and electrodes while the system is operating. Wear electrically insulating boots and gloves during field work. Disconnect cables from Terrameter / Electrode Selector before connecting / disconnecting electrodes to / from cables.

The operator must always keep all parts of the equipment including instrument, electrode selector, electrode cables, electrodes etc. under control for unauthorized persons and stray animals while the system is operating to avoid accidents!

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1 INTRODUCTION

This Instruction Manual covers operation, maintenance and, where appropriate, reduction of data. A careful study of this manual is recommended before starting to work with the equipment.

ABEM products are carefully checked at all stages of production and are thoroughly tested before leaving our factory. They should provide many years of satisfactory service if handled and maintained according to the instructions given in this manual.

ABEM will be pleased to receive occasional reports from you concerning your use of and experience with the equipment. We also welcome your comments on the contents and usefulness of this manual. In all communication with ABEM be sure to include the instrument types and serial numbers. Contact details:

Address: *ABEM Instrument AB, Allén 1, S-172 66 Sundbyberg, Sweden.*

Fax number: *+46 8 28 11 09*

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E-mail: *sales@abem.se* or, if you have technical questions, *support@abem.se*.

Information about ABEM's product range is available on internet: *http://www.abem.se*. Also the most recent version of interpretation software are available on: *www.abem.se*.

In general, e-mail correspondence gives the fastest response.

In view of our policy of progressive development, we reserve the right to alter specifications without prior notice.

IMPORTANT

It is important that you as a user of the instrument notify ABEM about your name and address. This allows us to keep you updated with important information about the instrument and e.g. upgrades of the built-in software and documentation. Please send your name and address directly to ABEM, utilize the Warranty Registration Card delivered along with the instrument.

1.1 UNPACKING AND INSPECTING

Use great care when unpacking the instrument. Check the contents of the box or crate against the packing list that is included. Inspect the instrument and accessories for loose connections and inspect the instrument case for any damage that may have occurred due to rough handling during shipment.

1.1.1 Shipping damage claims

File any claim for shipping damage with the carrier immediately after discovery of the damage and before the equipment is put into use. Forward a full report to ABEM, making certain to include the ABEM delivery number, instrument type(s) and serial number(s).

All packing materials should be carefully preserved for future re-shipment, should this become necessary.

1.2 WARRANTY

ABEM warrants each instrument manufactured by them to be free from defects in material and workmanship. ABEM's liability under this warranty is limited in accordance with the terms of General Conditions for the Supply of Mechanical, Electrical and Associated Electronic Products (ORGALIME). It covers the servicing and adjusting of any defective

parts (except tubes, transistors, fuses and batteries). The Warranty is effective for twelve (12) months after the date of Bill of Lading or other delivery document issued to the original purchaser, provided that the instrument is returned carriage paid to ABEM, and is shown to ABEM's satisfaction to be defective. If misuse or abnormal conditions have caused the fault, repairs will be invoiced at cost.

Should a fault occur that is not correctable on site, please send full details to ABEM. It is essential that instrument type and serial number is included and, if possible, the original ABEM delivery number. On receipt of this information, disposition instructions will be sent by return. Freight to ABEM must be prepaid. For damage or repairs outside the terms of the Warranty, ABEM will submit an estimate before putting the work in hand.

Be sure to fill in the warranty registration card (included with the equipment) correctly and return it to ABEM promptly. This will help us process any claims that may be made under the warranty. It will also help us keeping you informed about e.g. free software upgrades. ABEM welcomes your response at any time. Please let us know your name and address, and the serial number of the instrument.

1.3 REPACKING AND SHIPPING

ABEM packing is designed for the instruments concerned and should be used whenever shipping becomes necessary. If original packing materials are unavailable, pack the instrument in a wooden box that is large enough to allow some 80 mm of shock absorbing material to be placed all around the instrument. This includes top, bottom and all sides. Never use shredded fibers, paper or wood wool, as these materials tend to pack down and permit the instrument to move inside its packing box. **Do not return instruments to ABEM until shipping instructions have been received from ABEM.** Contact ABEM on fax number +46 8 28 11 09 or support@abem.se.

1.4 Compliance

The Terrameter SAS 1000 / 4000 and the accessories are in conformity with the essential requirements in the Low Voltage Directive 73/23/EEG, 93/68/EEG and the Electromagnetic Compatibility Directive 89/336/EEG of the EC.

2 GENERAL

The Terrameter SAS system consists of a basic unit called the Terrameter SAS 1000 or SAS 4000 which can be supplemented as desired with accessories such as the ABEM LUND electrode systems and the ABEM SAS LOG 300 borehole logging unit. This manual covers the operation of SAS 1000 and SAS 4000 as well as these accessories.

SAS stands for Signal Averaging System - a method whereby consecutive readings are taken automatically and the results are averaged continuously. SAS results are more reliable than those obtained using single-shot systems.

- SAS 1000 / 4000 can be used for resistivity surveys, IP surveys and self-potential surveys.
- The ABEM LUND system is an automatic electric imaging system, suited for automatic resistivity, IP and SP profiling.
- The SAS Log 300 (optional) provides an efficient, simple way of extending your survey into wells and drill holes. It consists of a 300m cable with logging probe, electrodes, temperature transducer, water level indicator and resistivity cell, all mounted on a backpacking frame.

The applicability of the different resistivity and IP methods supported by the SAS 1000 /4000 is summarized in table 2-1 below.

Object of search or investigation	SP	VES	Imaging	IP
Archeological sites			X	
Cavities in subsurface			X	
Clays, peat and soil	X		X	
Dam safety and leakage	X		(X) ¹	
Fissures in rock			X	
Fracture zones in rock			X	
Groundwater in crystalline rock			X	
Groundwater in sedimentary areas		X	X	
Groundwater / clay distinction			X	X
Groundwater flow	X			
Ores in hard rock areas	X		X	X
Overburden thickness		X	X	
Pollution of soil and groundwater			X	
Saltwater invasion		X	X	X
Waste mapping / characterisation			X	X

Table 2-1: Applicability of different resistivity and IP methods. Modified from Parasnis (1997)². SP=Self Potential, VES=Vertical Electrical Sounding, Imaging=Profiling (with different electrode separations), IP=Induced Polarization.

¹ Monitoring.

² Parasnis, D. S., Principles of Applied Geophysics, 5 edition, 1997. Chapman & Hall.

2.1 TERRAMETER SAS 4000 - THE SYSTEM

The Terrameter SAS 4000 system consist of the following components:

- SAS 4000 instrument with four input channels
- External Battery Adapter
- RS 232 cable (with KPT connector to SAS 4000 and DSUB connector to PC)
- USB to DSUB adapter
- Documentation kit (two sets of Operators Manual, Warranty Registration Card)
- CD with software

2.2 TERRAMETER SAS 1000 – THE SYSTEM

The Terrameter SAS 1000 system consist of the following components:

- SAS 1000 instrument with one input channel
- External Battery Adapter
- RS 232 cable (with KPT connector to SAS 1000 and DSUB connector to PC)
- USB to DSUB adapter
- Documentation kit (two sets of Operators Manual, Warranty Registration Card)
- CD with software

2.3 TERRAMETER SAS 1000 / 4000 - GENERAL

The Terrameter SAS 1000 / 4000 can operate in three modes:

- In the resistivity surveying mode, it comprises a battery powered, deep-penetration resistivity meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions. Discrimination circuitry and programming separates DC voltages, self potentials and noise from the incoming signal. The ratio between voltage and current (V/I) is calculated automatically and displayed in digital form in kilohms, ohms or milliohms. If array geometry data is available, apparent resistivity can be displayed. The overall range thus extends from 0.05 milliohms to 1999 kilohms.
- In the Induced Polarization mode the SAS 1000 / 4000 measures the transient voltage decay in a number of time intervals. The length of the time intervals can be either constant or increasing with time. The IP effect is thus measured in terms of chargeability [msec V/V].
- In the voltage measuring mode, the SAS 1000 / 4000 comprises a self potential instrument that measures natural DC potentials. The result is displayed in V or mV. Optional non-polarisable electrodes are available for e.g. self potential surveys.

A useful facility of the Terrameter SAS 1000 / 4000 is its ability to measure in four channels simultaneously. This implies that as well resistivity and IP measurements as voltage measurements can be performed up to four times faster. The electrically isolated transmitter sends out well-defined and regulated signal currents, with a strength up to 1000 mA and a voltage up to 400 V (limited by the output power 100 W). The receiver discriminates noise and measures voltages correlated with transmitted signal current (resistivity surveying mode and IP mode) and also measures uncorrelated DC potentials with the same discrimination and

noise rejection (voltage measuring mode). The microprocessor monitors and controls operations and calculates results.

In geophysical surveys, the SAS 1000 / 4000 permits natural or induced signals to be measured at extremely low levels, with excellent penetration and low power consumption. Moreover, it can be used in a wide variety of applications where effective signal/noise discrimination is needed.

It can be used to determine the ground resistance of grounding arrangements at power plants and along power lines and (in a pinch) it can even be used as an ohmmeter. The strength of the SAS 1000 / 4000 is its ability - thanks to the induced polarization mode - to distinguish between geological formations with identical resistivity, e.g. clay and water.

Some of the highlights in the specifications characterizing the SAS 1000 / 4000 Terrameter are listed below:

- Resolution 1 μ V (at 1 sec integration time)
- Bitstream A/D conversion
- Three automatically selected measurement ranges (± 250 mV, ± 10 V and ± 400 V)
- Dynamic range as high as 140 dB at 1 sec integration time, 160 dB at 8 sec integration time
- Precision and accuracy better than 1% over whole temperature range
- Galvanic separated input channels (SAS 4000)
- Built-in PC compatible microcomputer
- More than 1,000,000 data points can be saved on the internal flash disk
- Fast and highly time-efficient data acquisition

2.4 TYPES OF MEASUREMENT SUPPORTED

The transmitted current is commutated in a waveform suitable either for resistivity surveying or for induced polarization measurements.

2.4.1 Resistivity measurements

The receiver measures the response voltage signal (plus self-potential and ground noise) at discrete time intervals when the eddy currents, the induced polarization and the cable transients have decayed to low levels.

The operator can select between different time scales. Under most conditions a cycle time of approximately 2.6 sec (which corresponds to an acquisition delay of 0.2 sec and an acquisition time of 0.3 sec) will work fine. However, under extreme depth and resistivity conditions the corresponding time cycles should be increased. Under normal conditions the measuring technique is equivalent to pure DC surveying.

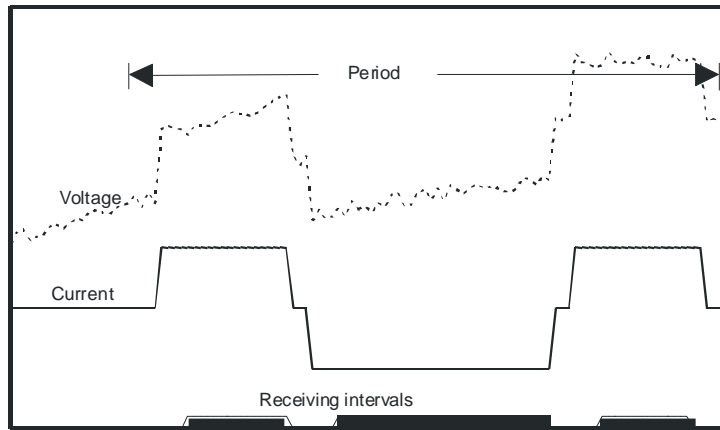


Figure 1. Timing diagram of the Terrameter SAS 1000 / 4000 in resistivity mode. The full-drawn curve shows the transmitted current, and the dotted curve an example of the measured voltage in the presence of noise. The three receiving intervals are shown at the bottom line.

The current amplitude is set automatically by the instrument, but can also be controlled by the operator to suit the actual survey conditions. It can be set to values from 1 mA up to 1000 mA. The maximum voltage at the current electrodes is 400 V. It is recommended to use the AUTO setting, which implies that the instrument sets the optimum value.

In the resistance measuring mode, the Terrameter SAS 1000 / 4000 measures voltage responses created by the transmitter current while rejecting both DC (SP) voltage and noise. The ratio V/I is automatically calculated and displayed digitally in kilohms [k Ω], ohms [Ω] or milliohms [m Ω]. The relevant receiver resistance range is automatically selected.

The result is displayed to 3 or 4 digits. When the transmitter is operating at 500 mA, the Terrameter SAS 1000 / 4000 has a resolution of 0.02 m Ω for a single reading.

To take full advantage of the outstanding capabilities of the Terrameter SAS 1000 / 4000, care must be observed in the arrangement of cables and electrodes used in the field. Current leakage and creep can substantially reduce the attainable accuracy and sensitivity and thus the depth penetration.

2.4.2 Induced polarization mode - Chargeability

In IP mode the current is transmitted symmetrically, i.e. that the positive and negative polarities are of equal length. A complete cycle consist of one positive part of length T (called current on) and one negative part of the same length T (current off). This time can be set to the following values: 1, 1.5, 2, 2.5, 3, ... sec in steps of 0.5 sec.

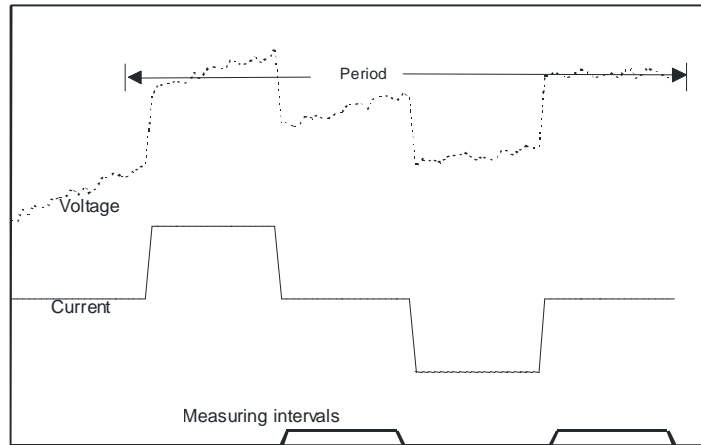


Figure 2. Timing diagram of the Terrameter SAS 1000 / 4000 in IP mode. The full-drawn curve shows the transmitted current, and the dotted curve an example of the measured decaying voltage in the presence of noise. In this example there is almost no IP effect. The two receiving intervals are shown at the bottom line. Each measuring interval can consist of up to ten time windows.

As in resistivity mode the current amplitude is set automatically by the instrument, but can also be controlled by the operator. It can be set to values from 1 mA up to 1000 mA. The maximum voltage at the current electrodes is 400 V.

In the induced polarization mode (IP) the SAS 1000 / 4000 measures the transient decay of the voltage when the transmitted current is turned off. The voltage is integrated over a number of time intervals, and the SAS 1000 / 4000 can measure in up to ten such time intervals. The total integration time is limited to 8 sec. The first interval starts after the initial time delay Δt_d . The length of the different time intervals can be expressed by the relation

$$\Delta t_i = n \cdot f^{i-1} \Delta t_0$$

where

- Δt_0 is the fundamental time interval (20 msec in areas with 50 Hz main power frequency, respectively 16.67 msec in areas with 60 Hz power frequency)
- n is a multiplying factor (default = 1)
- $f = 1$ or 2 (default $f = 2$) is an incremental exponent
- i is the time window index (1, 2, ..., 10)

Four parameters are needed in order to specify the way SAS 1000 / 4000 measures the induced polarization:

- The initial time delay (10, 20, 30, msec). Default is 10 msec. Maximum is 10 sec.
- The length of the first time window (column one in the tables below). Default is 100 msec.
- The number of time windows (from one to ten). Default is 1.
- The incremental factor: 1 corresponding to the first of the tables below, 2 corresponding to the last of the tables.

Window number (incremental factor = 1)									
1	2	3	4	5	6	7	8	9	10
20*	20*	20*	20*	20*	20*	20*	20*	20*	20*
100	100	100	100	100	100	100	100	100	100
200	200	200	200	200	200	200	200	200	200
500	500	500	500	500	500	500	500	500	500
1000	1000	1000	1000	1000	1000	1000	1000		

*Table 2-2: The length of each of the time window (measured in msec) when the incremental factor is 1. The * indicates that in countries with 60Hz power line frequency, the value is 16.67 msec in stead of 20 msec.*

Window number (incremental factor = 2, power line frequency = 50 Hz)									
1	2	3	4	5	6	7	8	9	10
20	40	80	160	320	640	1280	2560		
100	200	400	800	1600	3200				
200	400	800	1600	3200					
500	1000	2000	4000						
1000	2000	4000							

Table 2-3: The length of each of the time window (measured in msec) when the incremental factor is 2. This table is valid in countries with 50Hz power line frequency.

Window number (incremental factor = 2, power line frequency = 60 Hz)									
1	2	3	4	5	6	7	8	9	10
16.7	33.3	67	133	267	533	1067	2133		
100	200	400	800	1600	3200				
200	400	800	1600	3200					
500	1000	2000	4000						
1000	2000	4000							

Table 2-4: The length of each of the time window (measured in msec) when the incremental factor is 2. This table is valid in countries with 60Hz power line frequency.

Whenever the sum of the time windows in use exceeds the current on (off) time T, this time is extended so that the current off time exceeds the sum of the active time windows plus the initial time delay. Observe, that the total integration time cannot exceed 8 sec. This explains the "white" area in the tables above.

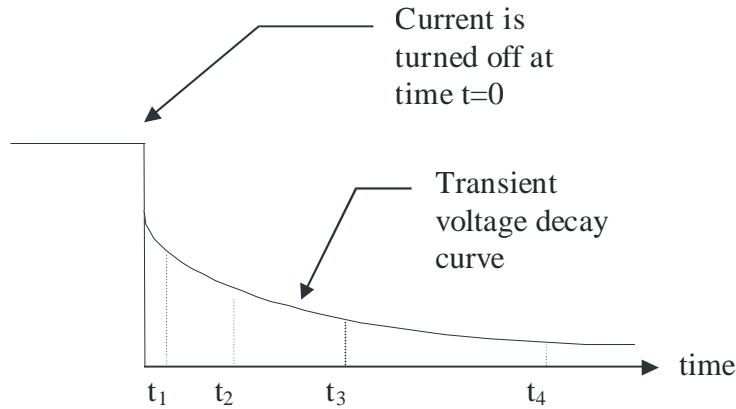


Figure 3. The IP decay curve. The chargeability is measured as the area between two time values. For example $M_{20,40}$ represents the chargeability measured in the interval between 20-40 msec. The delay before the measurements starts are denoted by $t_D = t_1$

The SAS 1000 / 4000 measures the time-domain quantity called chargeability $M_{t_i, t_{i+1}}$ defined in the following way:

$$M_{t_i, t_{i+1}} = \frac{1}{V_0} \int_{t_i}^{t_{i+1}} V(t) dt \quad [\text{msec}] \quad (1)$$

where $V(t)$ is the decaying voltage, t_i and t_{i+1} is the start and stop time of the interval, and V_0 is the voltage measured before the current is turned off. The terminology refers to figure 2. The chargeability is measured in the unit *msec*. Alternatively, the chargeability can be presented as *mV/V*:

$$M_{t_i, t_{i+1}} = \frac{1}{V_0(t_{i+1} - t_i)} \int_{t_i}^{t_{i+1}} V(t) dt \quad [\text{mV/V}] \quad (2)$$

For further reference on the chargeability, see e.g. Parasnis³ chapter 5.

³ D. S. Parasnis, Principles of Applied Geophysics, 5. edition, 1997. Chapman and Hall.

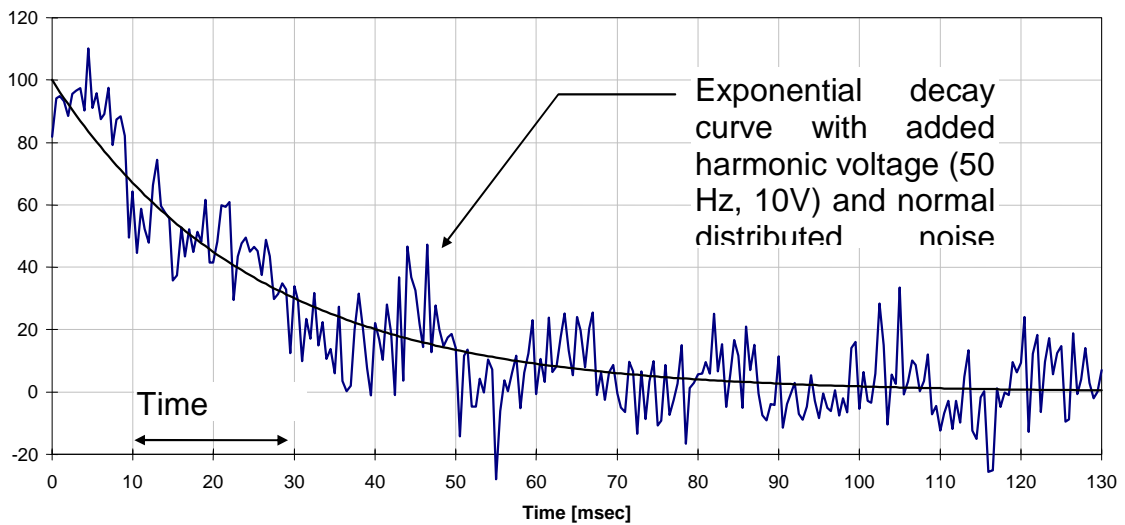


Figure 4. Synthetic example illustrating the noise reduction effect in the chargeability. In this example the difference between the chargeabilities $M_{10,30}$ measured from 10 msec to 30 msec on the smooth exponential decay curve and the "noisy" curve is only 2%.

Figure 3 is a synthetic example illustrating the noise reduction effect of the chargeability. In the figure is shown an exponential decay curve $100\exp(-t/\tau)$ with the decay constant $\tau=25$ msec. Also shown is the decay curve with added harmonic power-line voltage (50 Hz, 10V) and normal distributed noise with standard deviation 10V.

Integration over a time window, e.g. 10-30 msec, shows that the chargeability is only little affected by the noise. In this particular example the deviation is 2.3% between the true exponential decay curve and the curve superimposed with noise.

2.4.3 Negative readings?

Negative resistivity readings can occur, but in general, these are not caused by geological formations if standard electrode arrays are used. Hence, negative resistivity readings are normally a sign of serious measurement quality problems, and the cause should be investigated. Typical causes are poor electrode grounding resulting in low transmitted power and possible capacitive coupling. If the ground is dry the electrode contact must be improved by e.g. watering and possibly connecting several electrodes to each electrode point. Inspect all connectors and cable jumpers for dirt, oxide and damage that may cause data quality problems. High noise level or the influence from close-by objects like fences or steel pipes in electrical contact with the ground might also cause non-expected results.

Negative IP readings, on the other hand, are to be expected in many cases, even though the intrinsic chargeability never can become negative. On a stratified ground negative IP readings can occur in certain cases when the subsurface layer is more conducting relative to the upper

layers. This (paradoxical) behaviour is explained quantitatively in the literature⁴. Near-surface objects can also cause negative IP readings, see e.g. Principles of Applied Geophysics⁵ section 5.6.

2.4.4 DC potential measurement (SP)

If the SP option is chosen in the Main Menu, DC potential (self-potential) measurements can be done. Thanks to extremely linear circuits, the voltage can be read and displayed to 3 or 4 significant digits.

The basic integration interval is 20 msec (16.66 msec in countries with 60 Hz power line frequency). This integration gives an effective reduction of noise. In areas close to electric railways with 16 2/3 Hz frequency it is recommended to select 100 msec integration interval.

The Terrameter SAS 1000 / 4000 calculates either the mean or the median value (default). The standard deviation of the measurements are also calculated and presented. Statistically distributed voltage noise is thus reduced by a factor of \sqrt{N} , where N is the number of readings. Measure time can be 1 - 8 sec in steps of 0.1 sec.

2.5 TECHNICAL LAYOUT OF THE SAS 1000 / 4000

The SAS 1000 / 4000 is equipped with a PC-compatible microcomputer and controlled by four knobs (Figure 5). Each knob is mounted on a peg, fixed in the instrument panel, and the motion of the knob is transferred magnetically. This ensures waterproof sealing.

For a detailed description of the user interface, please refer to chapter 3. The program allows the user to specify the measuring parameters in detail, and even put comments on the data files. However, for those who want simply to take a reading, there is no need for setting parameters. Just hit the red knob.

⁴ Nabighian, Misac N., and Elliot, Charles L., Negative Induced-Polarization Effects from Layered Media, Geophysics 41, 6A, p1236-1255.

⁵ Parasnis, D.S., Principles of Applied Geophysics, Fifth Edition 1997, Chapman and Hall.

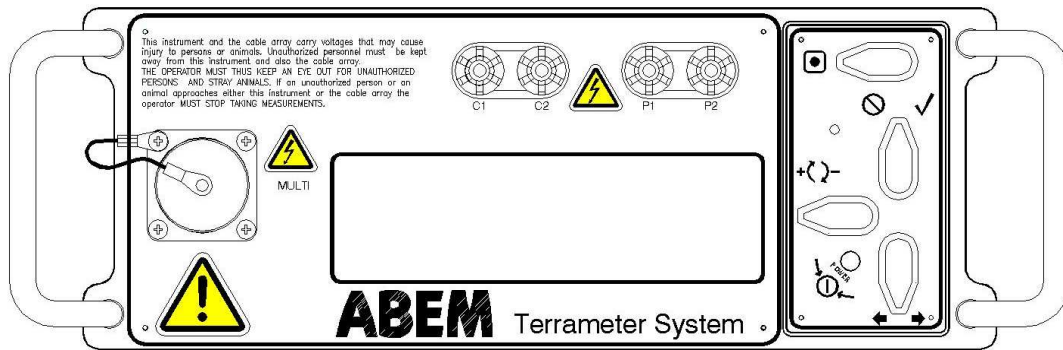


Figure 5: The Terrameter panel with display (centre), control knobs (right), multi purpose communication and signal connector (left), and current and potential terminals (top). On older SAS 4000 instruments there may be additional communication connectors.

2.5.1 Current and potential connectors

For measurements utilizing only one channel (out of the four channels) it is often easier to use the four "banana" connectors labelled C1, C2, P1 and P2. These connectors are localized above the instrument display. In cases where more channels are needed, the MULTI connector has to be used. The C1, C2, P1 and P2 "banana" connectors are connected in parallel to the corresponding pins in the MULTI connector.

To connect more than one set of potential electrodes, use the Multi Channel Adapter (optional accessory for the SAS 4000).

2.6 ACCESSORIES

2.6.1 The LUND Resistivity Imaging System

The LUND system is a multi-electrode system for high-resolution 2D and 3D resistivity surveys. It consists of a basic unit, the Electrode Selector ES464, ES10-64eC or ES10-64C, and multi-conductor cables. The system can be controlled directly from the SAS 1000 / 4000. Among the powerful features you will find:

- 64 electrodes unrestricted switching in a compact, battery-operated unit.
- Robust, waterproof design for reliable operation in harsh environments.
- Designed to link to the Terrameter SAS 1000 / 4000 with one single cable.

- Robust data-acquisition software featuring:
 - Automatic measurement process.
 - Automatic roll-along with coordinate updating.
 - Electrode cable geometry and switching sequence defined in address and protocol files allow user-defined surveying strategies and arrays. Files are supplied for Wenner, Wenner-Schlumberger, multiple gradient array, pole-dipole, dipole-dipole, pole-pole and square-array measurements.
 - On-screen echo of measurement progress
- Software for graphical presentation including:
 - Pseudosection plotting in colour or grey-scale.
 - Optionally available 2D inversion software for automatic 2D interpretation.

2.6.2 Terrameter SAS LOG 300

The Terrameter SAS LOG 300 logging system is intended for use together with the Terrameter SAS 1000 / 4000 system. It is intended for logging to depths down to 300m. It supports the following logging modes:

- Short normal (16") resistivity / IP
- Long normal (64") resistivity / IP
- Lateral (18") resistivity / IP
- Self potential
- Temperature
- Fluid resistivity (can be used to estimate TDS)
- Water level indicator

This simple, easy to transport, logging system makes it possible to delineate formation boundaries with regard to infiltration, porosity and permeability by means of self potential and resistivity measurements. Under favourable circumstances, water flow boundaries can be detected by measuring temperature changes. Moreover, the resistivity of the water can be measured in situ so that the total amount of total dissolved solids (TDS) can be estimated. Zones of high salinity can thus be localized and sealed off by means of casing and cementing.

3 OPERATING THE SAS 1000 / 4000

These operating instructions explain only how to handle the equipment itself. Instructions for conducting the different types of surveys are available in other documents.

3.1 CONTROLS AND TERMINALS

3.1.1 Controls

To turn on the SAS 1000 / 4000, press the two lower knobs towards each other as indicated by the ON/OFF symbol on the instrument panel. A LED (Light Emitting Diode) indicates that the instrument is starting, and after approximately 20 sec the start menu comes up on the display. During the start-up process of the SAS 1000 / 4000 you should avoid touching the knobs.

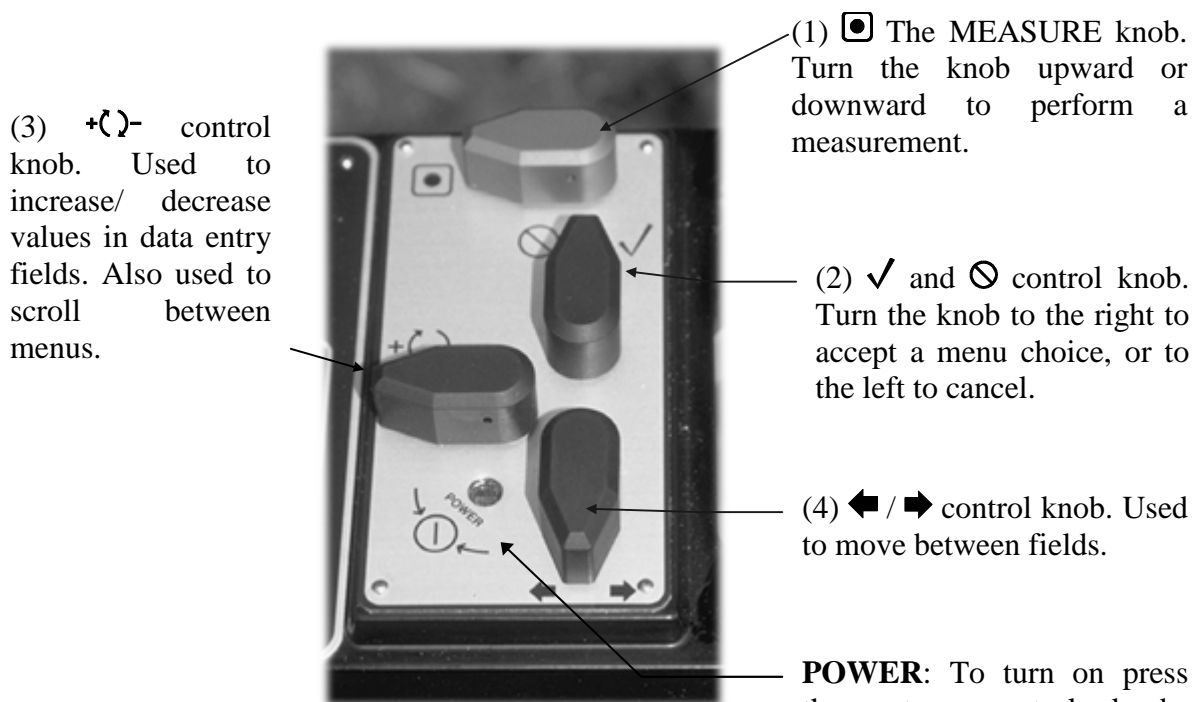


Figure 6: The control knobs on the SAS 1000 / 4000

Important: After turning on the instrument (using the two lower control knobs) the red LED (light emitting diode) will turn on, and the welcome menu will appear after 20-30 sec.

If the display does not become visible, please check the display contrast as described below.

To turn OFF, press the two knobs towards each other until the "Power OFF" dialog box appears on the screen, then accept OK. This will initiate the computer to close all files and safely switch off.

```

Measure para[RES:R00001] (|)Page 1/6
Output:      200 mA  Mode: Auto
Acq. delay
Acq. time:   Power off?
             <Ok>  <Cancel>
Total cycl
( [ ])=Measure (O)=Quit
    
```

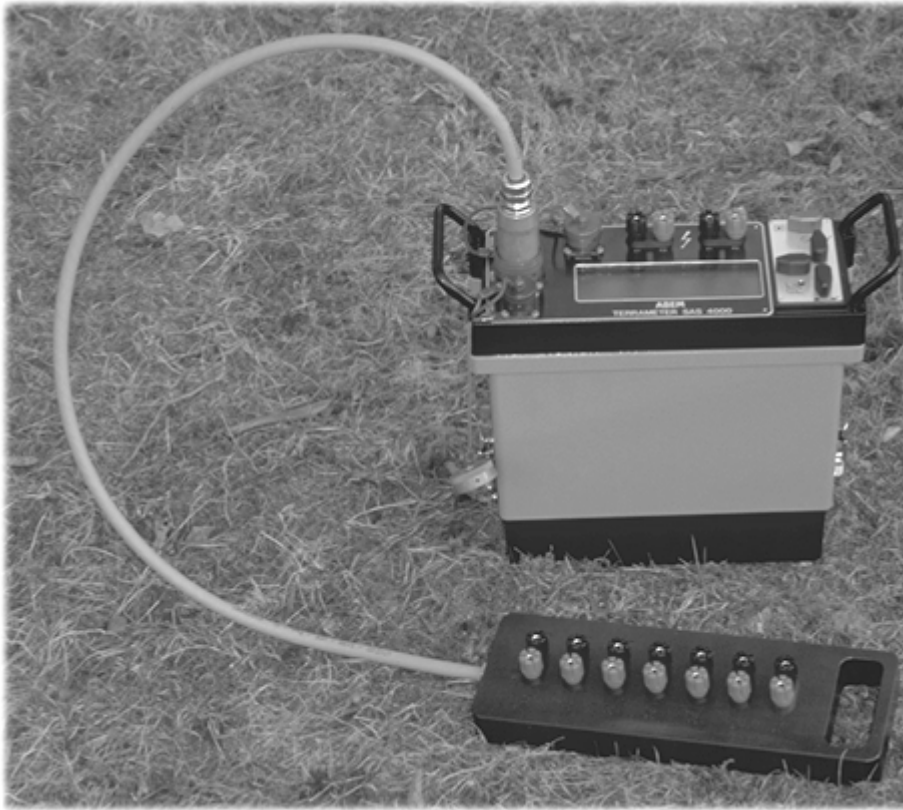
Keeping the two knobs towards each other for an extended period of time, will cut the instrument power regardless computer activities, data and settings may not be saved.

3.1.2 Special key sequences

- **Battery voltage and software build:** press ◀ / ▶ (4) and +↻- (3) away from each other. The battery voltage will then be displayed. Also the software build number is shown.
- **Program information:** press ⊙ (2) and +↻- (3) towards each other. This brings up information about program version etc.
- **Change the Display Contrast:** press ⊙ (2) and ◀ / ▶ (4) to the right (for darker display) or left (for lighter display) simultaneously to adjust the LCD contrast. **It is essential that both knobs are actuated at the exactly same time.** Keep the knobs in the left (or right) position for several seconds while the contrast successively changes. The purpose with the exact timing is to distinguish this action from any other action with the knobs. If an attempt fails, this might set the system into one of several dialog windows (so far invisible) and no further action but the precise answer in the dialog window is accepted by the software. It will now be necessary to turn the instrument off and try all over again. After turning on the instrument, wait 30 seconds for starting up.

3.1.3 Multi Channel Adapter (MCA)

The SAS 4000 Multi Channel Adapter (optional accessory) is connected directly to the MULTI connector on the SAS 4000. The adapter makes it possible to connect one pair of current electrodes (named CURRENT) and four pairs of potential electrodes (named CH1, CH2, CH3 and CH4). Furthermore the MCA contains four banana takeouts (named T1, T2, T3 and T4) intended for instrument test and calibration. Please refer to 9.5 for information about the instrument test.



The Multi Channel Adapter is used to connect more than one potential channel in e.g. vertical electrical soundings. In performing Schlumberger soundings it is very favourable to connect the four channels to potential electrodes separated by, say, 0.20 m, 1 m, 3 m and 10 m. Then the overlapping sounding curve segments, needed in Schlumberger soundings, are easily constructed afterwards. The Multi Channel Adapter is not delivered with the SAS 1000.

3.2 WARNINGS

3.2.1 Safety



Dangerous voltages and currents are transmitted by the Terrameter via the cables and electrodes connected to it! During the entire duration of an electrode contact test or measurement session it is the responsibility of the operator always to have full control of all equipment including the entire electrode cable layout, so that unauthorized persons and stray animals do not get close to the electrodes and measurement cables!

Due to the very high voltage in the current connectors on the SAS 1000 / 4000 it is dangerous for personnel and animals to get in touch with these connectors and cables. It is the responsibility of the operator to eliminate the risk for accidents with the instrument.

Some important steps to avoid accidents:

- The instrument and connected accessories should only be operated by instructed personnel.
- Keep unauthorized people and stray animals away from the instrument, connected accessories and cables.
- Also when running automatic data collection (with the LUND system) the operator is responsible for having full control of the entire cable layout.

3.2.2 Lightning

Note that semiconductors protect both the current and the potential terminal circuits. Lightning, high voltage cattle fence or other high voltage sources may, however, damage the instrument. Lightning miles away may induce hundreds of volts in long cable layouts, and this entails risk for both personnel and equipment.

You should never take measurements during a thunderstorm!

If a thunderstorm should come up while you are taking measurements, disconnect the cables from the terminals without touching any bare conductors. Never leave the cables connected to the SAS 1000 / 4000 overnight, since a thunderstorm may occur.

3.2.3 Heat

Although each individual Terrameter is tested by operating for at least one hour in a heat chamber prior to delivery, it is important to pay attention in order to avoid overheating. Thermal fuses will under normal operating conditions turn off the instrument if overheating occurs to prevent damage, but it will of course halt the measuring process.

Some precautions to avoid overheating:

- Never operate an instrument in direct sunlight, use a parasol or other device to keep it in the shade.
- Do not operate the instrument in small closed spaces, like for example transport boxes, where air cannot circulate freely.

Even if these precautions are taken production stops may occur when operating in hot climates. Various techniques may be employed to cool the instrument in order to keep up production. Cooling mats intended for e.g. laptop computers are recommended, these are flat

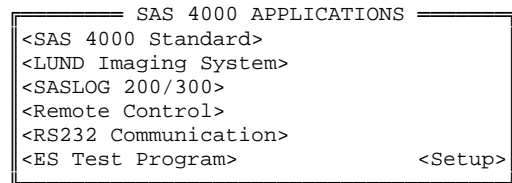
bags filled with a salt with high thermal capacity that can be placed in contact with the sides of the instrument.

Another option under extreme climate conditions is to lean the instrument and place a moist piece of cloth on the side of it; evaporation of the moisture will then give a good cooling effect. Similarly bags with ice have been used to cool instruments in the field. In any of these cases extreme caution must be taken to avoid electric shock from short circuit by water from the cooling device! The operator has the full responsibility for this!

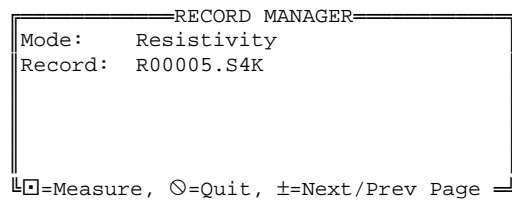
3.3 MANAGING THE CONTROLLING PROGRAM

A tour through the SAS 1000 / 4000 program

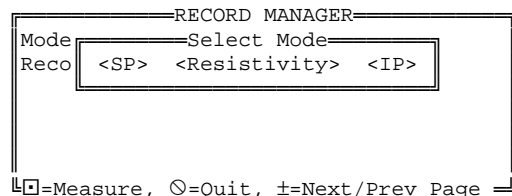
After turning on the instrument the welcome menu appears. This menu will only stay for a few seconds, until it is followed by the Applications menu. Select between the different sorts of measurements or the RS232 communication for download of data and update of software. Depending upon which program modules you have downloaded into the instrument, other options may appear. By selecting <SAS 4000 Standard> the next menu appears.



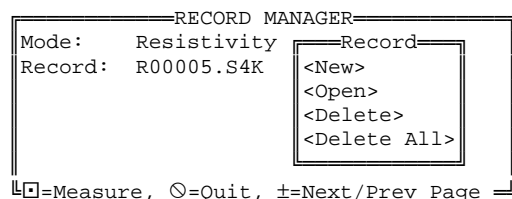
In the **RECORD MANAGER** menu you can select the measuring mode <SP>, <Resistivity> or <IP>. In the second entry field you can manage the record. Move between the fields with the ◀ / ▶ control knobs. The data are saved on a file named e.g. R00005.S4K. The first letter (in this case R) indicates it is resistivity data. In the case of self-potential the first character is S and in case of IP an I. The following five digits defines the record number and is automatically updated when a new record is defined. The number can be adjusted in the "New record" field by use of the editing knobs ◀ / ▶ and +(-).



To select a mode turn the ✓ knob and move between SP, Resistivity and IP by the ◀ / ▶ knob. Select a mode by pressing ✓.



To define a record, press the ✓ knob in the record field. This brings up the submenu, in which you can select a new record, open an existing, or delete record(s).



By selecting a new record the next menu appears. For VES with pre-defined protocols (see below) set "Layout:" to "Sounding", and "Method:" to "Schlumberger". The number of channels can be set to 1, 2, 3 or 4 (SAS4000 only). Go to this position and select with the \checkmark knob. Change the number with the $+(-)$ -knob. The power line frequency is important for noise reduction purposes: in countries with 60 Hz power line frequency set this to 60 Hz. Select the <Setup Layout Ref.> to define a reference point. Also the azimuth and inclination of the line can be defined here. Press the \odot knob (or select <Ok>) to continue to the Acquisition Settings menu.

```
(Res.) R00002.S4K
Method: Untitled
Layout: Untitled
No of channels: 4
Powerline freq.: 50 Hz
<Setup Layout Ref.>      Grid:      2.00m
      <Ok>      <Cancel>
```

The Acquisition Settings menu consists of 6 pages. Use the $+(-)$ -knob to navigate between the five pages. In this menu, select the output current. If Mode=Auto the program will automatically reduce the current if it is impossible to transmit the selected current.

```
Measure para[RES:R00002] (±)Page 1/6
Output:      200 mA Mode: Auto
Acq. delay:  0.3 sec.
Acq. time:   0.5 sec.

Total cycle time: 3.8 sec.
(  $\square$  )=Measure (  $\odot$  )=Quit
```

On this page the stacking parameters are defined. With the settings in the example, there will be max 4 stackings. If the standard deviation is below 1% after e.g. 3 stackings, the stacking will be stopped. The norm can be "Median" or "Mean". The first is more robust to blunders. Based on the geometry, the program can display the apparent resistivity if the last option is set to "Yes", and if array geometry parameters are available. The "Data buffer size" is the number of readings between each saving operation to the storage.

```
Stack param.[RES:R00002] (±)Page 2/6
Min. stacks: 1
Max. stacks: 4
Error limit: 1.0 %
Norm:      Median
View app. res.: No
Data buffer size: 20
(  $\square$  )=Measure (  $\odot$  )=Quit
```

Normally there is no need to change the parameters on this page.

```
Options[RES:R00002] (±)Page 3/6
Ignore error 4: No
Ignore error 5: No
Ignore error 22: No
Tx setup mode: Smart
(  $\square$  )=Measure (  $\odot$  )=Quit
```

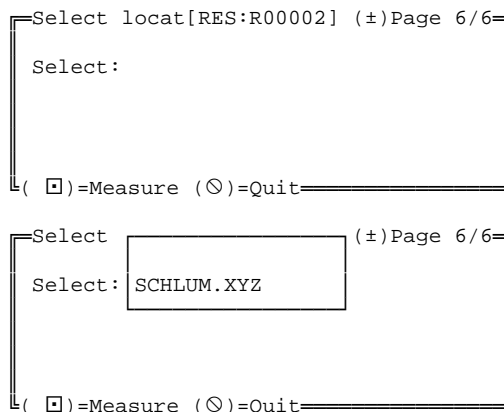
In this page information about the operator, client etc can be written. Select a row by \leftarrow / \rightarrow followed by \checkmark . Then write characters with the $+(-)$ -knob.

```
Infotext[RES:R00002] (±)Page 4/6
Operator:
Client:
Comm.#1:
Comm.#2:
Comm.#3:
Comm.#4:
(  $\square$  )=Measure (  $\odot$  )=Quit
```

From this page it is possible to select a channel and view all the measured data.

```
View samples[RES:R00002] (±)Page 5/6
Number of entries: 0
Select a channel to view:
=====
<Ch. 1>
Start at sample: 1
No. of samples: 100
(  $\square$  )=Measure (  $\odot$  )=Quit
```

It is possible to select pre-defined electrode geometries from a protocol file that has been uploaded using the “Transfer/Install XYZ file” option in the Utility software (see *Section 8.1.6 Format of VES Protocol Files*, page 62). Press to select the desired measurement protocol.



When you are finished, move to the measuring menu by pressing the knob.

By pressing the electrode separations menu is reached. If a pre-defined measurement protocol was selected, the <AB+> and <MN+> commands can be used to increase electrode separations, and <AB-> and <MN-> to reduce them. Otherwise the electrodes separations can be adjusted manually by pressing and using / and to step up or down the values.

Ch	P1	P2	Resistance	S.Dev%	Stacks
1:					
2:					
3:					
4:					
C:			I=Auto		
N=0			R00004.S4K	Free=100%	
Press (+/-) for more...					

Ch	P1	P2	Resistance	S.Dev%	Stacks
1:					
2:					
3:					
4:					
C:			I=Auto		
N=0			R00002.S4K	Free=100%	
Next: AB/2=0.56 Ch1MN/2=0.10 Press +/-					

Perform a measurement by pressing . The result is presented in this window.

3.4 MEASURING MODES OF THE SAS 1000 / 4000

The Terrameter SAS 1000 / 4000 can operate in different modes, Resistivity, Self Potential and Induced Polarization. In all modes the SAS 4000 is capable of measuring simultaneously in four channels. This makes it suitable for all sorts of resistivity surveys.

3.4.1 Statistical description - mean or median

The Terrameter SAS 1000 / 4000 can use either of two different metrics for describing the statistical characteristics in the data: mean or median. The mean value is simply the sum of the individual stacked values, divided by the number of stackings. The median is the value in the "middle" of the ensemble of stacked values. As an example, consider the following four readings: 12, 31, 13, 12

The mean value is 17 and the median is 12.5. It is obvious that the median is more stable against blunders. As default, the SAS 1000 / 4000 uses the median when presenting the result. For both metrics, the standard deviation is calculated and displayed (and saved on the file together with the measured value).

3.4.2 Voltage measuring mode (SP) surveys

Use non-polarisable electrodes only.

- Connect the voltage that is to be measured to terminals P1(-) and P2(+). If you are measuring self potential (SP), non-polarisable electrodes must be used. **Beware of thunderstorms!** Any high voltages from cattle fences or the like picked up by the cables connected to the SAS 1000 / 4000 can damage the instrument.
- Turn the power on.
- Check that the mode is set to SP, otherwise correct it. Define a new record if appropriate.
- Activate the Measure key to perform a measurement. Each measurement is added to the file automatically.
- Continue to next position to repeat the measurement.

3.4.3 Resistivity surveying mode

Stainless steel potential electrodes are preferable, although ordinary steel electrodes are acceptable. The following procedure is appropriate when performing resistivity soundings.

- Position the SAS 1000 / 4000 half way between the potential electrodes (M and N). Connect terminals P1 and P2 to terminals M and N respectively. Use an ABEM sounding cable set or a 2-conductor cable of good quality with the conductors separated at the electrode end.
- Connect the current electrodes (A and B) to terminals C1 and C2 respectively. Run these cables in parallel adjacent to the SAS 1000 / 4000, and arrange them symmetrically with respect to the potential electrodes. **Beware of thunderstorms!** Any high voltages (from cattle fences or the like) picked up by the cables connected to the SAS 1000 / 4000 can damage the instrument.
- Turn the power on. Select <SAS 1000 / 4000 Standard>.
- Check that the mode is set to Resistivity, otherwise select it. Define a new record if appropriate.
- Select Method, Layout etc. as described in *Section 3.3 Managing the controlling program*.
- Activate the Measure knob to perform a measurement. Each measurement is added to the file automatically.
- Continue to next position to repeat the measurement.
- Negative resistance readings can occur for two reasons:
 1. The current or the potential electrodes have been connected with reversed polarities.
 2. The noise level may be much higher than the signal level (long distances between A and B and low current). If this is causing single negative readings, signal averaging must be used.

User defined electrode geometries can be entered via protocol files, see section 8.1.6 *Format of VES Protocol Files* (page 62) for a description.

3.4.4 Induced Polarization surveys

It is preferable to use non-polarisable electrodes for the potential electrodes. However, stainless steel electrodes will work fine in many cases, even though the noise level is increased considerably. For IP soundings perform as described above in section 3.4.3, with the exception that you have to select IP mode instead of Resistivity.

It is preferable to use the AUTO setting for the output current. In IP surveys it is very important to eject as high current as possible. The chargeability can be measured in up to 10 time windows starting from 10 msec and upward (in steps of 20 msec), with a total duration of the measurement interval of 8 seconds. A general and convenient setting for the first time window is from 10 msec to 110 msec. Please see section 2.4.2 (page 6) for further information on how the chargeability is measured.

The IP readings are displayed in a window similar to the one used for display of resistivity results. The unit for the chargeability is ms (milliseconds).

Ch	P1	P2	Chargeability	S.Dev	Stk	.
1:	0	0	12.14 ms	1.2	4	.
2:	N/A					.
3:	N/A					.
4:	N/A					.
N=2		I=Auto				.
Resistivity: Untitled, Untitled						.
I00017.S4K			C1=		C2=	.

When measuring in IP mode also the resistivity is measured automatically. By activating the knob (downwards) the detailed information is displayed. Proceed with the **+↻-** knob to display the results for channels 2-4 (if measured).

Mode: IP	I=200 mA
Rec: I00017.S4K	V=42.11 V
Channel: 1	R=210.55 Ω
	M=12.14 ms
	S.Dev.=1.2
	Stks=4

Activating the **+↻-** again brings up detailed information about the decay voltages for each channel. The primary voltage is given in the first row. The decay voltages for up to six time windows are given in the following rows.

Ch.#1	Ch.#2	Ch.#3	Ch.#4
42.11 V	---	---	---
8.20 mV	---	---	---
2.44 mV	---	---	---
---	---	---	---
---	---	---	---
---	---	---	---

3.5 ACQUISITION TIMER

In all measurement modes (resistivity, IP and SP) and in as well standard measurements as LUND measurements, a timer function can be activated. This timer will automatically start a measurement at certain time intervals.

The Acquisition Timer is especially useful in monitoring applications. For example, you can make Self Potential readings at certain time intervals, or take a complete LUND Imaging layout each, say, four hours.

This is the standard measuring menu. When you press a measurement will be done. To activate the acquisition timer, press .

```

Ch  P1  P2  Resistance  S.Dev  Stacks  .
1:                                     .
2: N/A                                     .
3: N/A                                     .
4: N/A                                     .
N=0          I=Auto                       .
Resistivity: Untitled, Untitled          .
R00017.S4K          C1=          , C2=    .
    
```

This brings up four commands. The commands <Delete Last>, <Skip Next> and <Exit> are obvious. If you select <Set Timer> the next menu appears:

```

Ch  P1  P2  Resistance  S.Dev  Stacks  .
1:                                     .
2: N/A                                     .
3: N/A                                     .
4: N/A                                     .
N=0                                     .
Resistivity:                            .
R00017.S4K          C1=          , C2=    .

Command
<Delete Last>
<Skip Next>
<Set Timer>
<Exit>
    
```

In the Set Timer menu you can define the start time and date. The interval is the time in hours, minutes and seconds between the start of each measurement. If you define an interval shorter than the time needed for SAS 1000 / 4000 to perform a measurement, the next measurement will start immediately after the previous.

```

Set Timer
Start:      08/11/1999 13:30:00
Interval:  0000:00:01

[ ]=Measure, [O]=Quit, [+]=Next/Prev Page
    
```

The Set Timer menu has the same function and layout in the case of LUND measurements.

4 POWER SUPPLY

The SAS 1000 / 4000 is powered by either by a clip-on NiMH (NiCd for older units) battery pack or by an external 12V source. The SAS 1000 / 4000 consumes around 1000 mA whenever it is turned on. During current transmission, the consumption can be up to 20 A. For all practical purposes this implies that the SAS 1000 / 4000 can run up to one working day on the original power pack, provided the instrument is used for ordinary electrical soundings only and turned off between soundings, and provided no higher currents than 20 mA are used. In the case of automatic profiling using the LUND imaging system, involving thousands of readings per day, it is necessary to use an external (car) battery. The External Battery Adapter, EBA, replaces the NiMH Power Pack, and allows the instrument to be connected directly to an external 12 V source. The Terrameter SAS 1000 is delivered with this adapter only, and no NiMH power pack.

The external battery should be of sufficient capacity. Lead acid batteries of type car batteries, or better gelled/sealed lead-acid batteries that do not leak if turned over, of 25 Ah or higher can be used. For heavy duty use 60 Ah is recommended.

The battery pack, as well as the External Battery Adapter, clips conveniently onto the bottom of the instrument.

4.1 BATTERY PACK

Stored batteries lose their charge (self-discharge) gradually, and this takes place more rapidly at higher ambient temperatures. However, even if a battery loses all of its charge during storage, satisfactory operation can be restored after one or two charge/discharge cycles. During storage, batteries should be disconnected from instruments. Batteries can be stored at ambient temperatures ranging from -40 °C to +65 °C.

The NiMH battery pack has a capacity of 8 Ah.

Safety precautions

- DO NOT damage a battery pack or expose it to fire. It may burst or release toxic materials.
- DO NOT short circuit the battery since this will result in high discharge currents, causing dangerous heating.

Older battery packs with Ni-Cd battery cells

Since the batteries are sealed you will normally not come into contact with the electrolyte. You should nonetheless be aware that the electrolyte used in both sealed and vented Ni-Cd batteries is potassium hydroxide. If you should get it in your eye, even a small amount can cause serious injury. Immediate flushing with water for 15 minutes plus follow-up medical attention is absolutely necessary. If the electrolyte gets on your skin, use vinegar or some other mild acid for neutralization.

Finally, it should be remembered that the cadmium in a Ni-Cd battery is a toxic metallic element that should not be disposed of in the usual way, since it represents a serious threat to the environment. Follow the rules set up by the local authorities in your country for handling rechargeable batteries.

4.2 EXTERNAL 12 V BATTERY ADAPTER

The external battery adapter was delivered together with your Terrameter SAS 1000 / 4000.

When you need more power than available in the standard battery pack, the external battery adapter is a convenient solution. The external battery adapter allows the Terrameter to utilize an external 12V DC source, e.g. a car battery. The external battery adapter clips on to the Terrameter in the same way as the standard battery pack, but contains a connector for the 12V DC source. The external battery adapter contains a protective circuit that protects the Terrameter against wrong polarity. A 20A fuse inside external battery adapter will blow in case of wrong polarity, and a few spare fuses are supplied. Note that even if this fuse is blown it might be possible to start the instrument but it will not be fully functional. Please observe that the external battery adapter itself (when not connected to the Terrameter) is not watertight.

5 ELECTRODES AND CABLES

5.1 ELECTRODES

Two types of electrodes are available from ABEM:

- Stainless steel electrodes
- Non-polarisable electrodes

The purpose of an electrode is to establish electric contact between an electronic conductor (the cable) to an ionic conductor (the earth). All sort of electrodes generate "noise". This is of importance only at the potential electrodes. Noise is defined as the fluctuating voltage that appears between a pair of electrodes, placed so close that no other "natural" voltages appear. One way - among several other ways - to measure the electrode noise is to place two electrodes in a case filled with soil, and register the fluctuating voltage as a function of time. It appears that non-polarisable electrodes create much less noise than steel electrodes. Another observation is that stainless steel electrodes create less noise than electrodes made of ordinary steel. An example of noise recording made between two pairs of electrode, one non-polarisable (Pb-PbCl₂) pair and one of stainless steel pair, is shown in Figure 7. Note the large zero shift and change in time in the data recorded with the steel electrodes.

5.1.1 Steel Electrodes

Resistivity surveys can be conducted using current electrodes made of ordinary steel. Potential electrodes made of ordinary steel can also be used under favourable circumstances but here stainless steel is preferred.

ABEM electrodes are made of stainless steel.

5.1.2 Non-polarisable Electrodes

Self potential surveys require non-polarisable electrodes. Also Induced Polarization soundings are preferably measured with non-polarisable electrodes. The ABEM Terrameter type of electrode consists of a solid state gypsum rod, covered with a plastic cylinder. The gypsum contains lead-chloride (PbCl₂), and a solid lead rod is placed in the centre. This electrode does not need any special care. However, after using an electrode, always clean it and replace the electrode cover to prevent drying out.



WARNING: The content of the electrode is poisonous.

- Do not put the electrodes into your mouth
- Avoid direct contact with the electrodes - use protective gloves
- Wash your hands after any direct contact with the electrodes
- Keep the electrodes away from children
- Store safely, away from children
- Dispose off properly

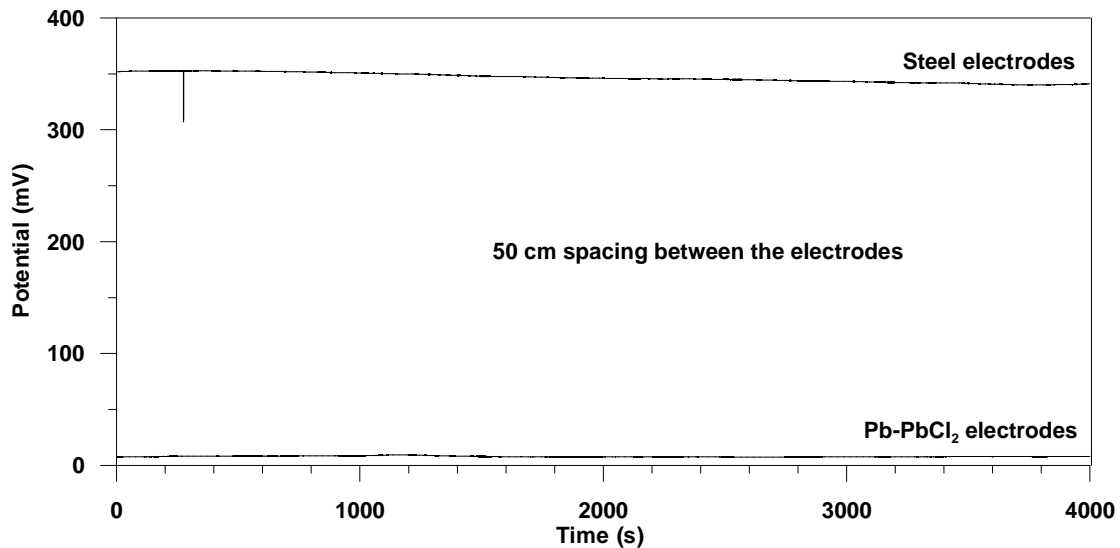


Figure 7. Potentials measured between a pair of Pb-PbCl₂ electrodes (lower curve) and a pair of steel electrodes (upper curve), showing typical difference in electrode noise.

5.1.3 Important remarks concerning current electrodes

Especially for the current electrodes it is very important with good galvanic contact with the soil. For small electrode separations (a few meters) it might be enough to stick the steel electrodes a few centimetres into the ground. For larger separations it is very important with a good grounding of the current electrodes. In dry conditions it is usually necessary to apply water around the electrodes. In the figure below is illustrated the relation between electrode burial and contact resistance, assuming that the ground is homogeneous in terms of resistivity. It is seen, that theoretically it is very favourable to bury the electrodes some 20-30 cm, whereas the profit of increasing the depth to, say, 60 cm is very limited. In a real situation, however, it is possible that the uppermost part of the ground is drier and more high resistive than underlying horizons, in which case it may pay off well to bury the electrodes deep enough to reach a moist zone.

In order to decrease the contact resistance it is possible to use more electrodes, connected in parallel. Provided the separation between the two electrodes to be connected is larger than the depth of burial, the contact resistance will be almost reduced by a factor of two. Similarly, three or more electrodes can be connected in parallel.

In dry and permeable soils, like sand, a common problem is that the water used to improve electrode contact is drained away before measurements are finished. In such cases it is useful to mix for example a starch compound (e.g. Johnson Revert intended to stabilise wells during drilling) into the water to make it more viscous, this can serve to keep the water in place for a sufficiently long time. Mixing salt into the water will further improve the ground contact.

Resistance in between electrode and soil

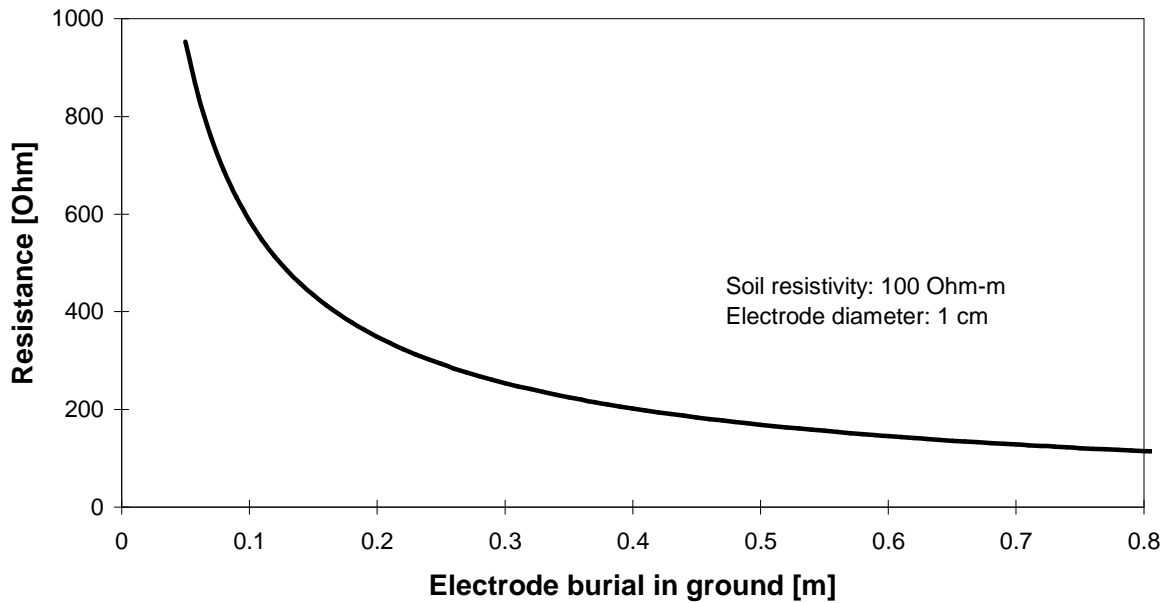


Figure 8. Theoretical relation between electrode burial and the contact resistance.

5.2 CABLE SETS

The standard Schlumberger and Wenner sounding cable set consists of

- 2 x 750 m current cable, 0.75 mm², on reel
- 2 x 250 m potential cable, 0.75 mm², on reel
- 2 x 2 m connection cable, red
- 2 x 2 m connection cable, black
- 4 crocodile clip
- 1 Plywood transport box

The sounding cable set is intended to facilitate Schlumberger and Wenner soundings. The cables incorporate heavy gauge conductors with excellent insulation to ensure good survey results. Moreover, there are convenient, short hook-up cables that reduce setup times and permit you to position the cable drums as desired.

Another important feature of the sounding cable set is easy expandability. If you need to run longer cables, for deeper penetration, you can purchase additional drums and connect them in series with your present drums.

6 LUND IMAGING SYSTEM

This chapter applies to the use of ABEM LUND Imaging System together with the Terrameter SAS 1000 / 4000. For use of the LUND Imaging System together with the Terrameter SAS 300, please refer to the LUND Instruction Manual, part no. 38 5002 83.



6.1 INTRODUCTION

6.1.1 Welcome to 2D and 3D Resistivity Surveying

Welcome to the ABEM Lund Imaging System, the multi-electrode system for cost-effective and high-resolution 2D and 3D resistivity surveys. The included data acquisition software supports 2D and 3D surveys with surface arrays, which may also be used borehole measurements.

The basic unit Electrode Selector ES464 / ES10-64eC / ES10-64C is a multi-channel relay matrix switch, which connects directly to the ABEM Terrameter SAS 1000 / 4000. Operating power comes from an internal 12 volt rechargeable NiMH battery pack (ES464) or via the Terrameter (ES10-64eC / ES10-64C).

Third party software packages for resistivity and IP data processing can be used for advanced interpretation. Please ask your authorized ABEM Distributor for details about resistivity interpretation packages that are available.

Your Lund Imaging System was carefully checked at all stages of production. It was thoroughly tested before being approved for delivery. If you handle and maintain it according to the instructions in the technical documentation, you will get many years of satisfactory service from it.

To ensure you get optimum results with ABEM Lund Imaging System, please take time to read this Reference Manual thoroughly. It gives you detailed step-by-step instructions for cost-effective field measurements. You should also look through this Reference Manual to

become familiar with its layout and contents. If you should, for any reason, have difficulties in operating ABEM Lund Imaging System or in getting satisfactory resistivity survey results, please contact your authorised ABEM distributor. ABEM always listens to end-user comments about their experience with ABEM products. So please send occasional reports on field usage as well as your ideas on how Lund Imaging System and its technical documentation could be improved to help you do an even better job of resistivity surveying.

6.1.2 Powerful Features

Among the powerful features you will find in ABEM Lund Imaging System are:

- 4x64 or 10x64 channels switching in compact unit.
- Robust waterproof design for reliable operation in harsh environments.
- Designed to link to the ABEM Terrameter SAS 1000 / 4000.
- SAS 1000 / 4000 data acquisition software featuring:
 - Automatic measurement process.
 - In-field quality control of measurements thanks to electrode tests and statistical measurement control.
 - Automatic roll-along with coordinate updating in x direction (Figure 9) or y direction.
 - Electrode cables geometry and switching sequence defined in address and protocol files allow user defined surveying strategies and arrays. Files supplied for standard and non-standard electrode arrays measurements.
 - On-screen echo of measurement progress.
- PC - software for download and conversion to several data formats:
 - Pseudosection plotting in colour or greyscale.
 - Model section plotting of inverted model sections in colour or greyscale including topography, reference data and reference levels (inversion software not included).
 - Graphical output in bitmap format.
 - Utility software for data conversion (e.g. to format used by 2D inversion software).

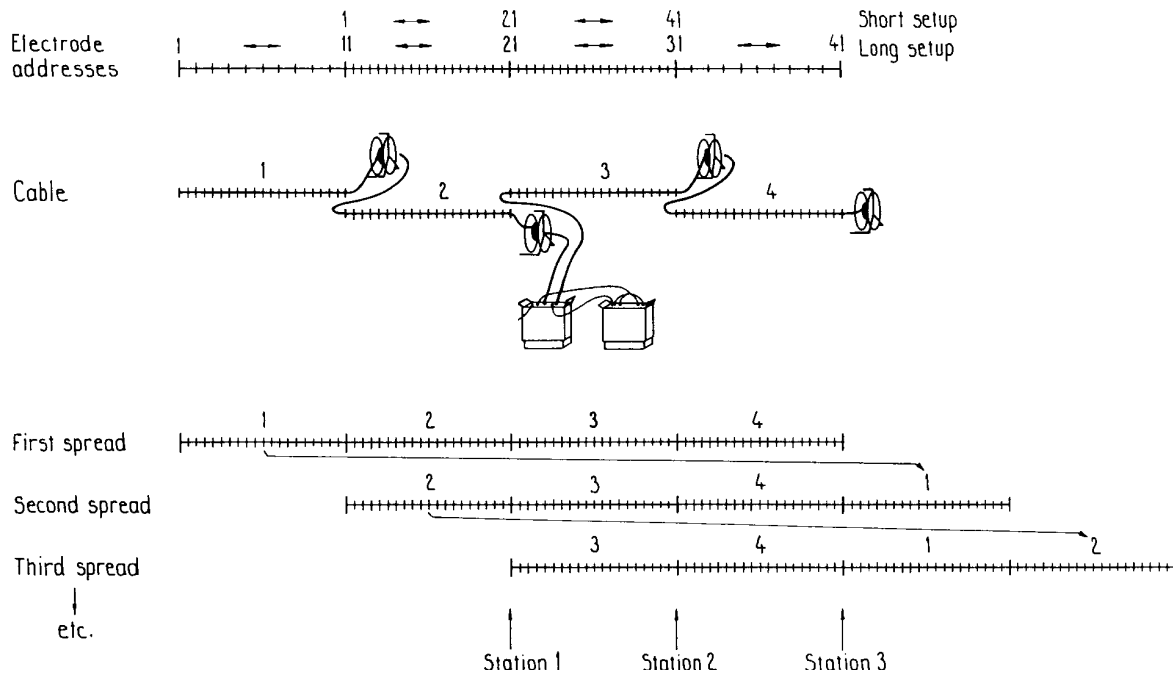


Figure 9. Sketch system layout for roll-along CVES surveying using four electrode cables. With 2 meter intervals between the electrode take-outs the system has a total length of 160 meter, with 5 meter intervals the total length is 400 meters.

6.1.3 Electrode Selector / Lund Imaging System

To operate the electrode selector with SAS 1000 / 4000 the boxes must be interconnected by the Multi-function cable, 33 0020 11. This applies for ES10-64eC, ES 10-64C and ES 464 delivered after September 1997.

Older ES 464 units delivered before September 1997 will need two cables: one Communication Cable for Electrode Selector to Terrameter, 33 0020 08 and one Current/Potential Cable, 33 0019 17.

Special connection cables

These two cables are used instead of the multi-function cable 33 0020 11 (not applicable to ES10-64):

- In the normal setup, as described above, only channel one in the SAS 1000 / 4000 is used. With an optional Pole-Pole cable, 33 0020 14 between the SAS 4000 and one unit ES 464 it is possible to perform pole-pole measurements using three measuring channels on the SAS 4000.
- With the optional Y-cable, 33 0020 15 it is possible to connect two ES 464 units to the SAS 4000. This allows for e.g. dipole-dipole measurements with three channels on the SAS 4000.

6.2 DATA ACQUISITION PROCEDURE

For general information on geoelectrical imaging please consult suitable geophysical textbooks⁶. A brief introduction is given in “Appendix A. Basic Principles of Resistivity surveying” (page 75).

6.2.1 Preparations for Field Surveying

Look through archive material for the area (topographical maps, geological maps, aerial photographs, reports etc.), and consider whether resistivity surveying is a suitable method for the current problem. If so, select possible profile lines.

Walk around the area to be surveyed with maps and/or aerial photographs at hand (aerial photographs and a pocket stereoscope is often highly useful) to select the optimal profile lines. Walk along the entire length of the planned profiles before putting out any equipment, to ensure that the selected lines are practical.

6.2.2 Essential Equipment

The following equipment is mandatory for data acquisition using the Lund Imaging System.

- ABEM Terrameter SAS 1000 / 4000
- To ensure proper function, SAS 1000 / 4000 should be powered from a gelled lead-acid battery or a car battery (25 – 70⁷ Ah).
- ABEM Electrode Selector ES 464 / ES 10-64eC / ES 10-64C, including connecting cable to Terrameter.
- Lund spread cables and suitable quantity of Cable Joints and cable jumpers.
- Suitable quantity of electrodes.

⁶ Examples of geophysical textbooks:

Parasnis, D.S. (1997) *Principles of Applied Geophysics*, 5:th ed, ISBN 0 412 64080 5, Chapman and Hall, London, 429p.

Reynolds, J.M. (1997) *An Introduction to Applied and Environmental Geophysics*, ISBN 0-471-95555-8, John Wiley and Sons, Chicester, 796p.

Sharma, P.V. (1997) *Environmental and Engineering Geophysics*, ISBN 0 521 57632 6, Cambridge University Press, 475p.

Telford, W.M., Geldart, L.P. and Sheriff, R.E. (1990) *Applied Geophysics*, 2nd ed., Cambridge University Press, 770 p.

Ward, S.H. (1989) Resistivity and Induced Polarization Methods, in *Investigations in Geophysics no. 5: Geotechnical and Environmental Geophysics, vol I*, ed. S. Ward, Society of Exploration Geophysicists, Tulsa, p 147-189.

⁷ A battery capacity of 60-70 Ah is recommended for heavy duty applications, i.e. continuous work for several hours with a high current setting.

6.2.3 Recommended Additional Equipment

Often additional equipment is required for efficient acquisition of good quality data. The following list is an attempt to summarize frequently needed additional equipment.

- It is strongly recommended to power SAS 1000 /4000 from an external gelled lead-acid battery or a car battery (25 – 70⁸ Ah) via an adapter.
- A set of walkie-talkies if cables with long electrode take-out spacing is used (i.e. more than 2 meters between each take-out).
- Polyurethane hammers of Stanley type (two or more) for hammering down electrodes.
- Plastic bottles for water with added salt and viscosity increasing polymer, to improve electrode contact in dry ground. A drill mud polymer (such as Johnson Revert or similar) added to the water can increase the viscosity to prevent draining away during measurement in permeable soils. Mix salt and polymer with water to suitable viscosity, it may be wise to do this in buckets before pouring the mixture into plastic bottles of convenient size.
- At least an additional double amount of electrodes and jumpers if operating in areas with dry ground giving contact difficulties.
- Spray paint and pegs to mark out profile lines.
- Non-metallic ruling tape to measure distance from profile line to reference objects, or to measure electrode spacing if smaller spacing than the take-out spacing are to be used.
- Levelling equipment and / or GPS receiver.
- Remote electrode cable(s) if pole-pole or pole-dipole array is used.
- Pocket multimeter with continuity check function for error detection.
- When working at a remote location it is recommendable to have a Tools and spares kit.

6.2.4 Field Procedure for 2D Electrical Imaging

Ensure that the batteries for the Terrameter and Electrode Selector are charged before going to the field! To ensure proper function, SAS 1000 / 4000 should be powered from a gelled lead-acid battery or a car battery of sufficient capacity.

The following field procedure assumes that the standard ABEM Lund equipment with a set of 4 cables with 21 electrode take-outs each is used.

For all protocol files using the standard Lund Imaging System cable layout, of four cables with 21 take-outs each, the procedure described below is recommended. By using this procedure, high near surface resolution towards the ends of the measured section is achieved. This is important not only for the resolution at shallow depths, but it also affects the resolution at depth.

At the first measurement station start laying out and connecting three cables only, and connect the instrument between the first two cables. In the data acquisition software these cables are designated as Cable 2, Cable 3 and Cable 4 (see Figure 10), where the instrument is connected between Cable 2 and Cable 3, and Cable 1 is excluded at the first station. Note that the last and the first electrode take-outs shall overlap at the cable ends.

⁸ A battery capacity of 60-70 Ah is recommended for heavy duty applications, i.e. continuous work for several hours with a high current setting.

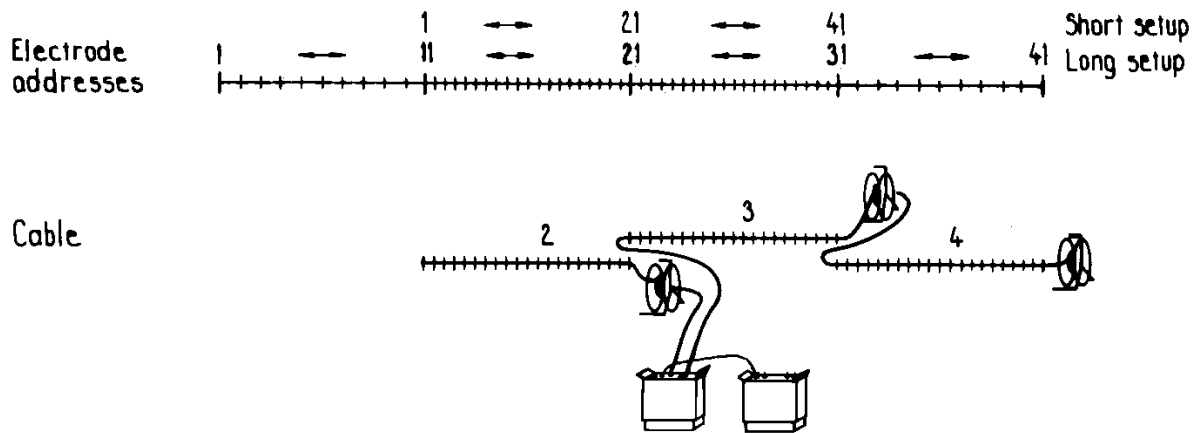
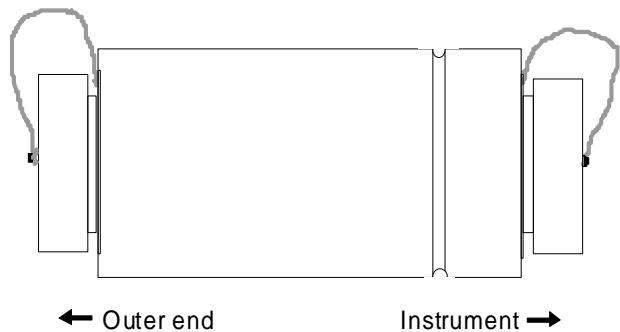


Figure 10. Cable arrangement at the first measurement station in a roll-along survey, where the first cable is excluded.

All CVES cables shall be rolled out in the direction of the profile, i.e. with the takeout numbers increasing in the same direction as the coordinate numbers increase. The procedure is: Secure the free cable end at the point of the lower coordinate number and walk the reel towards points of higher coordinate numbers. It is a good rule to have the profiles always running south-to-north or west-to-east (instead of north-to-south or east-to-west), to avoid confusion when the results are to be presented (unless an existing co-ordinate system demands else). Take-out # 21 of one shall overlap take-out # 1 of the next cable at the cable joints and in the layout centre. Overlapping takeouts connect to the same electrode.

Link together the inner and outer electrode cables (Cable 3 and Cable 4 only at this stage) with a cable joint (white cylindrical connecting device). Take care to connect it in the right direction: the groove on the cable joints should point towards the instrument in the layout centre.



Connect electrodes to the odd-numbered take-outs on all active electrode cables. The even-numbered take-outs can be left out for the time being. If the ground is soft and moist the electrodes can just be pushed into the ground and connected, however hammering and wetting is often needed. Check the contact surfaces between electrode take-outs, cable jumpers and electrodes for dirt and oxide, which can ruin the data quality, and clean if needed. Link together inner and outer electrode cables using the white cable joints.

Connect the Electrode Selector at the centre of the cable spread, i.e. between cable #2 and cable #3.

Note!

Moisture and/or dirt in the connectors may compromise the data quality and even cause permanent damage to the connectors. Always keep the protection caps clean and in place whenever possible. Let the protection caps protect each other when the cables are connected as shown in the picture.



Interconnect the Terrameter and Electrode Selector using the cable 33 0020 11 (alternatives as per paragraph 6.1.3). Turn on the SAS 1000 / 4000.

At the second measurement station, and all the following stations as long as the line is being extended, all four cables are connected (see Figure 11). Cable 1 is connected to Cable 2 with a cable joint as well, where again the groove must face the cable closest to the instrument.

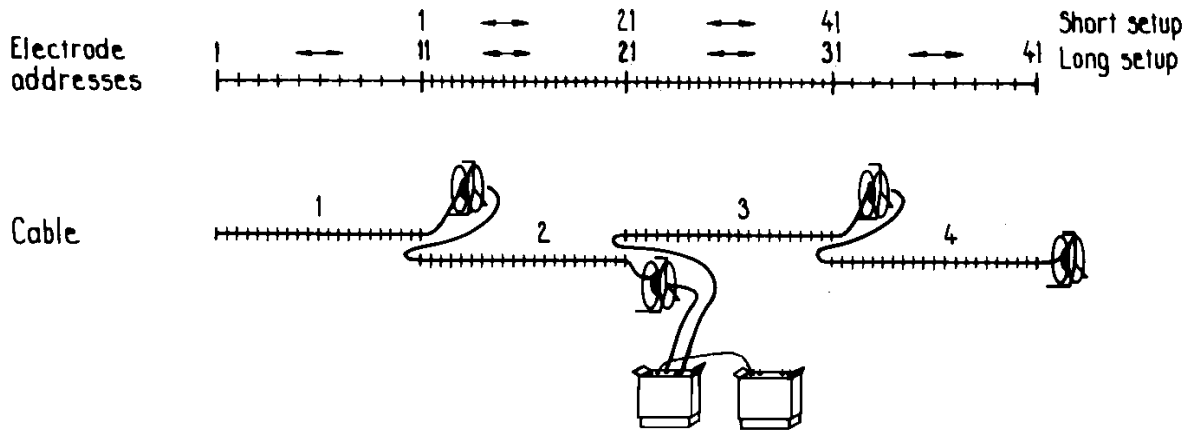


Figure 11. Cable arrangement at the second measurement station in a roll-along survey.

When finishing the measurement profile, and no additional electrode cable and electrodes are put out, the instrument should still be moved one step in order to get all the near surface information. The active electrode cables will thus be Cable 1, Cable 2 and Cable 3 (see Figure 12). Since all (for e.g. Wenner, Schlumberger and multiple gradient array) or many (for dipole-dipole or pole-dipole) of the possible measurements have already been done for the long layout protocol the measuring will be fast.

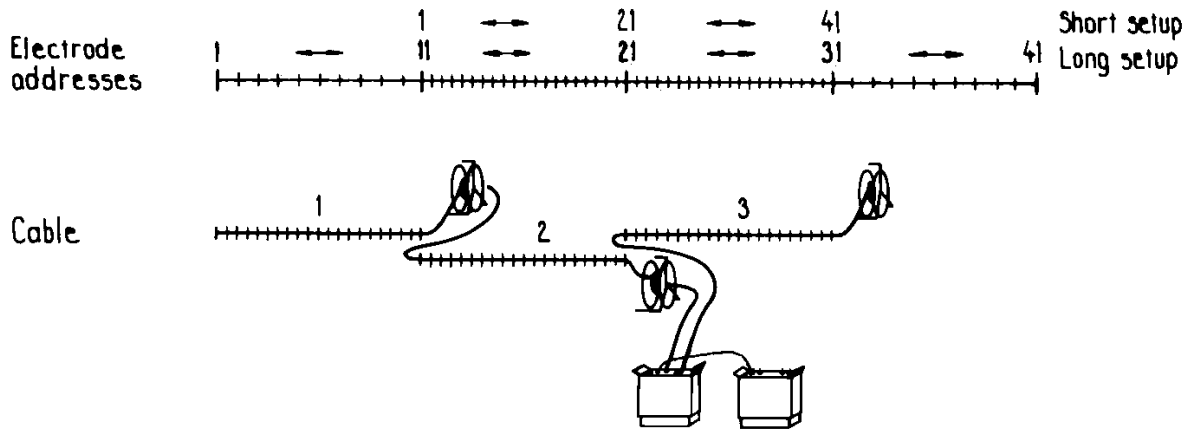


Figure 12. Cable arrangement at the last measurement station in a Wenner, Schlumberger or multiple gradient array roll-along survey, where the last cable is excluded.

If the multi-channel dipole-dipole or pole-dipole protocols mentioned in this document are used, it is necessary to do roll-along twice without adding new cable at end of line (see Figure 13). This depends on that these protocols are designed to avoid unnecessary repetition of measurements, and still get as much data as possible. Such a procedure need not be considered for single channel dipole-dipole or pole-dipole protocols. Notice that even if this procedure is used duplicate data points can occur for multi-channel pole-dipole protocols after roll-along.

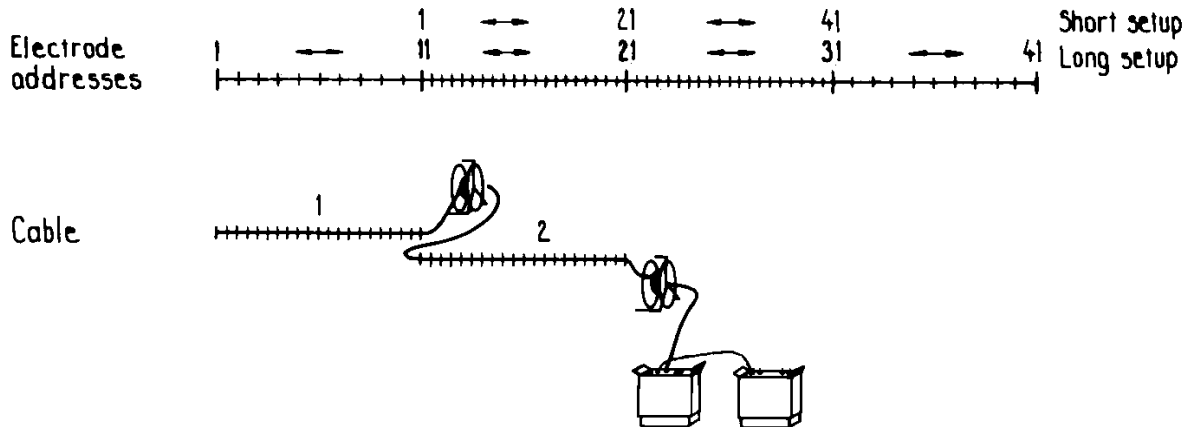


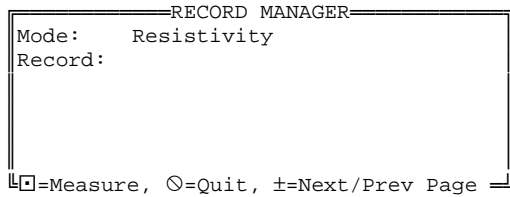
Figure 13. Cable arrangement at the last measurement station in a dipole-dipole or pole-dipole roll-along survey, where the last two cables are excluded.

For a cable set of 4 cables with 16 electrode take-outs each it is simpler. For nested electrode arrays (such as Wenner, Schlumberger and multiple gradient) all possible measurements can be taken with all 4 cables in one go. It is only for dipole-dipole and pole-dipole type of arrays measured with multi-channel equipment that it is motivated to consider using measurement protocols that require roll-along move of the instrument without adding new electrodes at the end of a surveying line in order to optimise the use of the multi-channel capability.

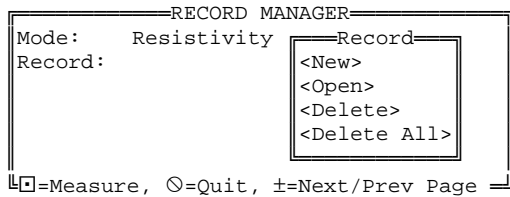
6.2.5 Using the LUND Imaging System Software

In the start-up menu select "LUND Imaging System" and press ✓. This starts the LUND program as described in the following.

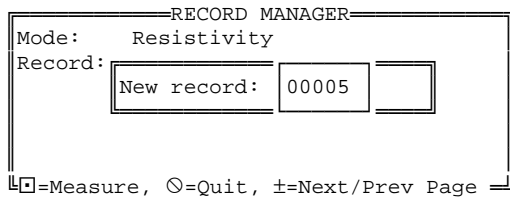
The first menu (after the welcome menu) is the Record Manager. Select the preferred mode (SP, Resistivity or IP).



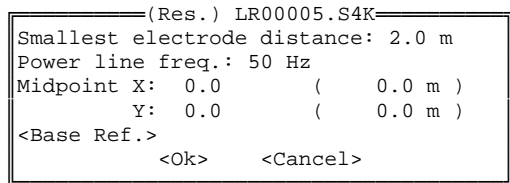
If you move to Record and press ✓ you get the options to create a new record, open an existing or delete record(s).



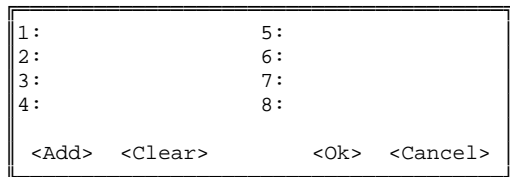
If you select "New" you get the option to name a new record. Either accept the default name, or define a new. Use the +↻- knob to change characters, and the ← / → knob to move between fields. If you name the record "00005", the record name will become LR00005. LR means LUND and Resistivity. If the mode was IP, the record name would become LI00005.



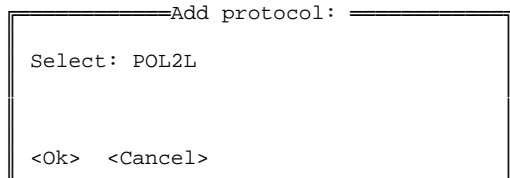
If you select a new record this menu appears. The smallest electrode distance is simply the electrode separation in meters. The power line frequency is either 50 Hz or 60 Hz. The midpoint coordinates can be given in units of electrode spacing. The base ref. is the coordinates and the azimuth/inclination of the origo of the base. To continue, select OK and press ✓ or simply press [Enter].



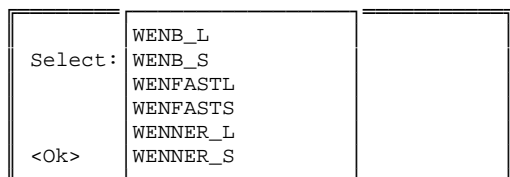
This brings up the menu where you select protocol file(s). At the first entry you have to select "Add" and press ✓.



Move to the "Select" entry and press ✓.



This brings up a list of all possible protocol file. In this list, move with the +↻- to a suitable protocol, e.g. Wenner_L. Then press ✓, and you are back in the menu shown above. Go to <Ok> and press ✓. The message "Validating protocol ..." will appear for a couple of seconds.



You are now back in the menu discussed above, but with the name of the selected protocol file written in position 1. In order to add one more file, select <Add> and go through the previous steps. In case you select incompatible protocols (e.g. WENNER_L together with SQUARE2A a warning will be given. A maximum of eight files can be specified. When ready, select OK or simply press .

```

1:WENNER_L      5:
2:WENNER_S      6:
3:              7:
4:              8:
<Add> <Clear>      <Ok> <Cancel>
    
```

A typical selection for one channel measurement is WENNER_L and WENNER_S, which is optimised for use together with the standard ABEM LUND cable, article no. 33 0019 25 or 33 0019 26. For four channel measurements the combination GRAD4L8 and GRAD4S8 is recommended.

The next menu is one out of a series of five menus. You can move between these five submenus with the +↻- knob. you have the option to specify measuring parameters. If you are satisfied, just press , otherwise select new values. By pressing +↻- you can move between four submenus. This is only of relevance if you need to change settings, e.g. number of stackings, error limit etc. A selection of a high current (200, 500 or 1000 mA) and Mode=Auto is recommended. The instrument will automatically step down to a lower current if it is impossible to transmit the selected current.

```

Resistivity: LR00004.S4K (PAGE/±)
Output:      1000 mA Mode: Auto
Acq. delay:  0.3 sec.
Acq. time:   1.0 sec.

Total cycle time:  5.2 sec.

=Measure, =Quit, ±=Next/Prev Page
    
```

In the second submenu you can specify the number of stacks. If the standard deviation during the measuring cycles passes below the error limit, the stacking is stopped. The norm can be either Median or Average, corresponding to the L1 and L2 metrics respectively. Finally, you can decide to show the apparent resistivity instead of the resistance.

```

Resistivity: LR00004.S4K (PAGE/±)
Min. stacks:  2
Max. stacks:  4
Error limit:   1.0 %
Norm:         Median
View app. res.: No
Data buffer size: 20

=Measure, =Quit, ±=Next/Prev Page
    
```

The data buffer size is the number of readings taken before saving to the disk. This value is a trade-off between speed and security.

In this third submenu some "internal" parameters can be controlled. It is advised not to change these default settings.

```

Resistivity: LR00004.S4K (PAGE/±)
Ignore error 4: No
Ignore error 5: No
Ignore error 22: No
Tx setup mode: Smart
Tx setup time: Fast

=Measure, =Quit, ±=Next/Prev Page
    
```

In the fourth submenu you decide whether or not to ignore negative readings and errors. You can choose to wait between protocol files. If you have access to an external alarm connected to the ALARM connector on the Electrode Selector, you can define whether or not to activate it.

```

Resistivity: LR00004.S4K (PAGE/±)
Ignore negative resistivity: No
Ignore errors 1-5: No
Wait between protocols: Yes
Use external alarm: No
    
```

☐=Measure, ○=Quit, ±=Next/Prev Page

In the fifth submenu you can define information about the measurements. Select a row by pressing the ✓ knob. Move between the characters and numbers by the +(-) knob.

```

Resistivity: LR00004.S4K (PAGE/±)
Operator:
Client:
Comm. #1:
Comm. #2:
Comm. #3:
Comm. #4:
    
```

☐=Measure, ○=Quit, ±=Next/Prev Page

In the sixth submenu you can select a channel to view on the screen (in this case there is only one channel available).

```

Resistivity: LR00004.S4K (PAGE/±)
Number of entries: 0
Select a channel to view:
=====
<Ch. 1>

Start at sample: 0
    
```

☐=Measure, ○=Quit, ±=Next/Prev Page

When you turn to start the measurement, a menu appears in which the results are displayed. Also the actual battery voltage is displayed here.

```

Ch P1 P2 Resistance S.Dev Stacks.
1: .
2: N/A .
3: N/A .
4: N/A .
N=0 I=Auto Batt=12.4 V
Resistivity: Wenner-a, Section .
LR00004.S4K C1= , C2= .
    
```

When you turn once again the Measurement Setup menu appears. Here you can select if the electrode test should be performed (recommended), and you can select the minimum output current. It is NOT recommended to step down the current level below 20 mA unless necessary, since the signal-to-noise ratio will inevitably suffer, with decreasing data quality as a result! For extra long electrode layouts a higher minimum current is recommended. The coordinates of the setup can be specified here also. If you know that certain electrodes must be excluded, select <Skip Electrodes> and deactivate the electrodes you do not need. In the upper frame the number of LUND units is given (1 or 2).

```

Setup (1 unit)
Protocol #1: WENNER_L.ORG
Electrode test: No
Min. output: 20 mA
Midpoint X: 0.0 ( 0.0 m )
Y: 0.0 ( 0.0 m )
<Skip Electrodes> <START> <CANCEL>
    
```

The Skip Electrodes Menu allows you to skip certain electrodes.

```

<< Skip Electrodes Menu >>
Protocol #1: WENNER_L.ORG .
#1 On 1-3-5-7-9-- .
#2 On 1-3-5-7-9-- .
#3 On --3-5-7-9-1 .
#4 On --3-5-7-9-1 .
Cable #1 takeout #1: Enabled .
( ○=Close ) .
    
```

To accept, press the (or select the <START> option). This start the electrode test (if you have selected "Electrode test: Yes" above) or the measuring procedure (if you have selected "Electrode test: No"). It is recommended that you use the electrode test function. When the test is finished, a list of the electrodes with bad ground contact is given. You then have the option to skip a particular electrode, or to improve the grounding. It may be necessary to connect several electrodes to each take-out to get sufficient contact

Ch	P1	P2	Resistance	S.Dev	Stacks.
1:					.
2:	N/A				.
3:	N/A				.
4:	N/A				.
N=0			I=Auto		.
Resistivity: Wenner-a, Section					
LR00004.S4K			C1=		C2=



NOTE: Dangerous voltages and currents are transmitted by the Terrameter via the electrode cables connected to the Electrode Selector! During the entire duration of an electrode contact test or measurement session it is the responsibility of the operator always to have full control of the entire electrode cable layout, so that people and animals do not get close to the electrodes and electrode take-outs connected to the measurement cables!

6.2.6 Electrode Test

If the electrode test (as described above) is set to *Yes*, the system checks if it is possible to transmit current through all electrodes. This test only takes a couple of minutes, but can save a lot of time afterwards!

The array code determines how the contact test is performed. For most arrays the electrodes can be tested pair-wise against each other starting at one end. Another option is to test each electrode against all the other electrodes (only available for ES10-64). For pole-pole and pole-dipole all the electrodes are tested individually since one of the current electrodes is assumed to be a remote electrode.

If long cables (e.g. with 5 meters or more between take-outs) are used a set of walkie-talkies are useful for efficient work, otherwise a lot of time may be wasted running up and down the cables.

The program automatically continues to measure using all four electrode cables when the contact is satisfactory. Occasionally, the program may stop depending on poor electrode contact even if the contact test was passed (depending e.g. on drying out, or that two "half-poor" electrodes are used together). It is therefore advisable to check that measurements have not stopped every now and then, and improve contact (or step down the current for that particular electrode combination only). It may be wise using a one step higher "lowest permissible current" during the Electrode Test and then return the value to the ideal, before the measuring starts.

6.2.7 Speed Up the Field Procedure

A good way to speed up the field procedure is to have one extra electrode cable and a generous supply of electrode and cable jumpers available, so that the extra cable can be rolled out and hooked up to electrodes while measurements are in progress. In this way the instrument and cable joints can simply be moved one step before starting the roll-along measuring on the following measurement station. If no extra electrode cable is at hand the following procedure can be adopted.

While the measurements are in progress for the long layout (using all four cables) the electrodes for the remaining take-outs on the two electrode cables closest to the centre (short layout) may be connected. When measurements are done for the long layout, the program stops and waits for the operator to press to continue with protocol file #2 if "Wait between protocols" is set to YES.

As soon as the measuring on the long layout is finished, Cable 1 can be disconnected, wound up and rolled out ahead of Cable 4 (if you want to perform roll-along). In this way all electrodes can be in place when measurements on the short layout are finished. Bring along the cable joint used to link Cable 1 and Cable 2 and drop it at the Electrode Selector. Disconnect the other cable joint when passing the connection between Cable 3 and Cable 4, and use it for linking the former Cable 1 when it is in place in the position ahead of Cable 4. Make sure that what is now Cable 3 and Cable 4 are linked together with a cable joint, unless it is the last station on the profile and Cable 4 hence is excluded.

When all measurements on the short layout are finished, the program stops and asks whether to continue with roll-along measurements (upward or downward) or quit. If you want to link more data to the profile, first disconnect Cable 2 and Cable 3 from Electrode Selector, and link these cables together with the cable joint. These cables are from now Cable 1 and Cable 2! Move Electrode Selector and Terrameter to the new centre point, and connect what is now Cable 2 and Cable 3 to Electrode Selector.

If you decide to continue with roll-along (up or down) the Measurement Setup menu appears again. The same comments as described previous applies. The process now continues as described above: checking of contact and measuring first for long layout and then short layout. However, measuring is now faster since many possible measurement combinations were already measured in the previous layout. While measuring is carried out on the long layout all electrodes at even-numbered take-outs on Cable 1 can be removed and connected to the even-numbered take-outs on Cable 3, to be ready for the contact test for the short layout.

The profile can be extended as far as desired. In addition measuring can be stopped at any time by pressing , which gives a possibility to change certain parameters in the setup. The measurement can then be continued, by pressing the key.

While measuring the profile, do not forget to take notes of the position of reference points along the line using the cables as ruler. Do also mark out some of the used midpoints along the profile with pegs, sticks, paint or whatever is suitable. This facilitates identification of points for further investigations later on. Furthermore, it is often efficient to level the topography while doing the measurements, using the cables as ruling tape. Similarly it can be efficient to determine the coordinates of key points along the measured line with GPS during the measurement process, unless this is taken care of by a special arrangement.

It is possible to stop the measuring program at any point, and re-start it again. You can select an existing record and add data to this record. The program will automatically find out how far the surveying has proceeded, update coordinates etc. It is thus possible to continue surveying without losing data after e.g. a power failure, or to extend a profile the next day. A profile can be extended either towards increasing coordinates (up) or decreasing coordinates

(down), but the cables must always be rolled out with increasing takeout numbers in parallel with increasing coordinate numbers.

6.2.8 Data Cover

The data cover for resistivity surveying with cable systems in general is dependent on several factors such as: the total number of electrode take-outs, the number of sections the cable array is divided into, the measurement array type used (Wenner, pole-pole, dipole-dipole etc.), and whether there are any restrictions on how the electrodes can be combined. This section shows the data cover of standard Wenner CVES, while “Appendix E. Address and Protocol Files” (page 89) summarizes the characteristics of protocol files supplied with Lund Imaging System.

For the standard Wenner CVES the data cover is enhanced by measuring in two sets, linking in electrodes from the outer electrode cables. This is demonstrated by the protocol files WENNER_L and WENNER_S. With roll-along measuring the data cover becomes continuous, for all but the longest electrode separations where there are gaps in the cover between the station points (Figure 14). Since there is a substantial over-lap in data cover between consecutive station points, the .UP and .DWN protocol files are reduced accordingly, which means measuring is much faster. In practice, this means that the measuring for these points normally take about half as long time as for the first midpoint. WENNER_S is designed only to supplement WENNER_L for the shortest electrode spacing, and is generally not suitable for use alone if only the two central cables are used. If measuring with two cables only use a protocol dedicated for this (see “Appendix E. Address and Protocol Files”).

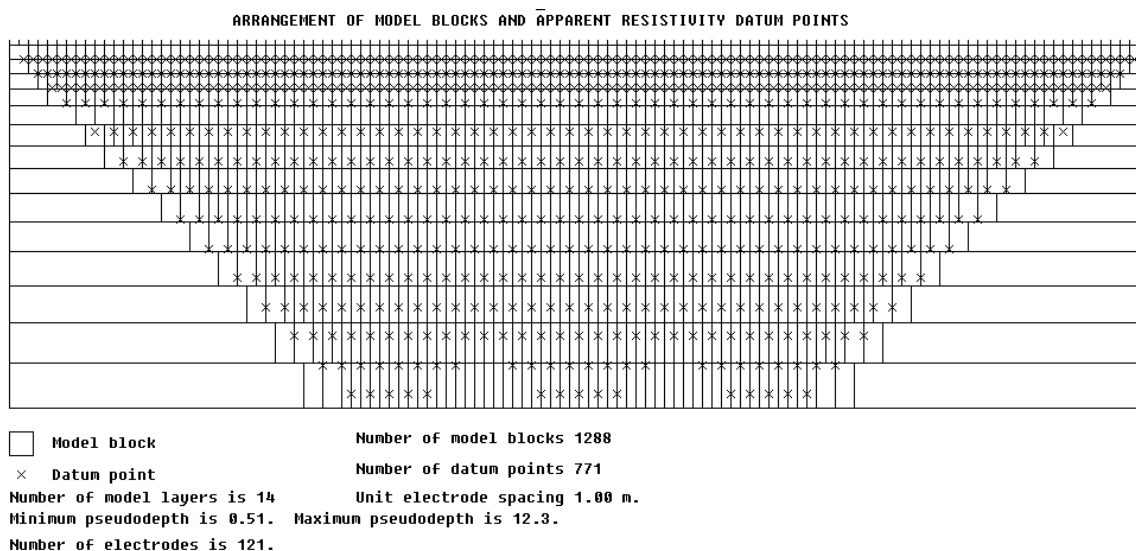


Figure 14. Data coverage of standard Wenner CVES, using the measurement protocols WENNER_L and WENNER_S, for roll-along with three full measurement stations, plus one station with a cable excluded at each end of the line. A unit electrode spacing of 1 metre was used.

Any cable configuration and electrode array could in principle be used for measuring, as long as the geometry and measuring sequence is specified in the address and protocol files used. Details on the format of these files are given in section 8.1.5 “Format of Lund Imaging Address, Protocol and Location Files” (page 59).

The SAS 1000 / 4000 displays measured resistance or apparent resistivity values on the screen during data acquisition, as well as the smallest inter-electrode distance and the midpoint coordinate.

6.2.9 Area Cover / 3D Roll-along

For applications where area coverage is needed it may be desirable to do roll-along in a direction perpendicular to the extension of the cables, as shown in Figure 15.

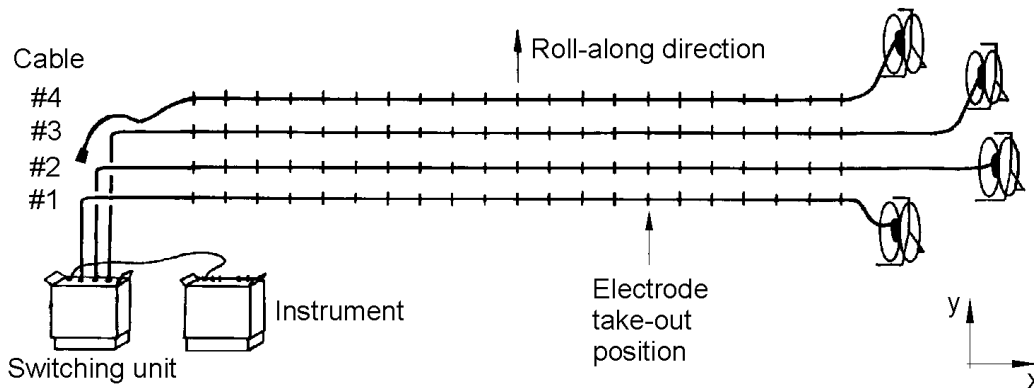


Figure 15. Sketch system layout for roll-along surveying, with a roll-along direction perpendicular to the cable direction. The roll-along direction will depend on coordinate system orientation preferences.

6.2.10 3D Resistivity Surveying by Means of a Number of 2D Layouts

A simple way of carrying out a 3D survey is to measure a number of parallel, and optionally orthogonal, 2D sections, and afterwards merge the 2D data sets into a 3D data set before inverting the data. A condensed step-by-step description is given below, in which it is assumed that the (first) electrode cable layout direction is called X and the perpendicular direction is called Y (Figure 16). The description assumes that Res3dinv is to be used for the inversion, but the procedure should also be applicable to alternative inversion software.

1. Decide the number of electrodes in the cable layout direction (X-direction). This will be limited by the number of take-outs on the electrode cables available, and could be for example 16, 21, 32 or 41 electrodes.
2. Decide which electrode configuration to use. Pole-dipole (both forward and reverse measurements) is often preferred as it offers good depth penetration and sensitivity towards the edges on limited cable layouts, plus good resolution. Dipole-dipole or multiple gradient array measurements are good options if it is not practical to use a remote electrode.
3. Select suitable protocol files and ensure that these are available to the Lund data acquisition software in the Terrameter (if necessary compile a PROTOCOL.BIN file and upload to the instrument).
4. Roll out the electrode cable(s) along the first investigation line and connect the electrodes. Connect the electrode cable(s) to the Electrode Selector and start measuring to a "New" data file using the selected protocol file(s).

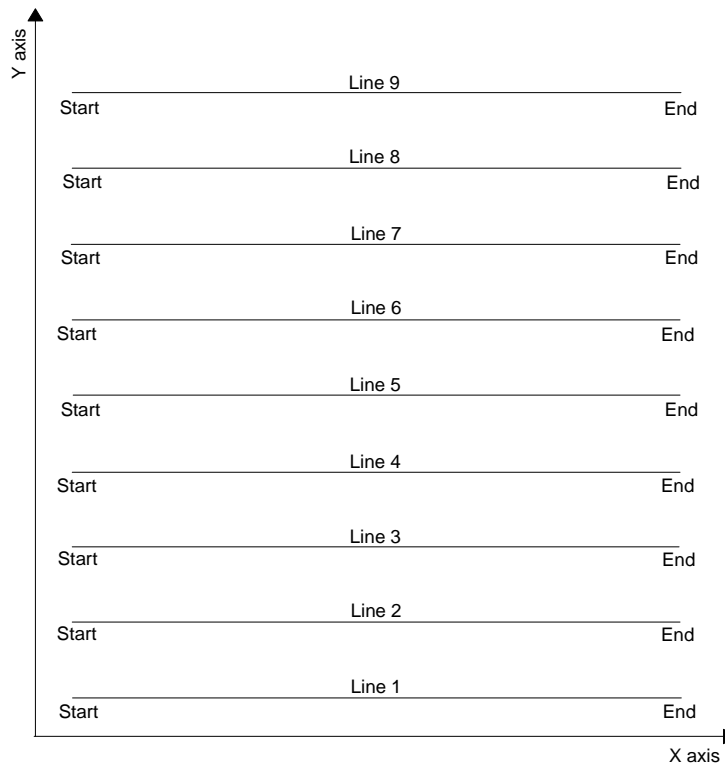


Figure 16. Example showing a survey consisting of 9 parallel lines oriented in the x-direction. In this case, according to the nomenclature of Res2dinv collate tool, all lines have the same X location of first the electrode along this line, but different Y locations. The line direction is zero in all cases ($0=X, 1=Y$), and the line direction/sign is also zero ($0=positive, 1=negative$).

5. While measuring is being carried out, electrode cable(s) can be rolled out and electrodes connected on the next investigation line. The distance between lines should normally not exceed twice the electrode separation.
6. When measuring is finished on the first line, select “Quit”, disconnect the Electrode Selector and move it and the Terrameter to the second line. Start a “New” data file and proceed with measuring as above.
7. Remove the cable(s) and electrodes from the first line and set up the third line. Continue this process as far as desired.
8. Using a separation between the lines that is equal to the electrode separation will increase the resolution. If extra resolution is required the process can be repeated with the electrode cables rolled out in the perpendicular direction (Y-direction).
9. After data acquisition is completed, download all the data files to a computer using the utility software. Convert the data files to the DAT-format used by Res2dinv.
10. Make a copy of the file COLLATE_2D_TO_3D.TXT (can be found in the Res2dinv program directory) and change filenames and coordinates according to the present survey. Start Res2dinv and use the option “File/Collate data into Res3dinv format” to merge the files.
11. Start Res3dinv and invert the merged data file.

6.2.11 Borehole Measurements

Borehole measurements require electrode cables designed for this purpose, standard Lund Imaging System electrode cables are not suitable. Address files must be designed to suit the

particular hardware configuration of these cables, and protocol files should use array code 12 (tomography). See section 8.1.5 “Format of Lund Imaging Address, Protocol and Location Files” (page 59) for more information on address and protocol files. The roll-along feature will not work for this type of measurements.

6.2.12 Possible Sources of Error

A number of possible problems, common sources of error/reasons and suggested measures are listed below. Suggestions for additions to this list are appreciated.

N.B. Moisture and/or dirt in the connectors will conflict the field work and even cause permanent damage to the connectors. Always keep the protection caps clean and in place when ever possible.

N. B. To ensure proper function, SAS 1000 / 4000 should be powered from a gelled lead-acid battery or a car battery (25 – 70⁹ Amp. hours) during the field work.

<i>Problem</i>	<i>Reason</i>	<i>Remedy</i>
No signs of life from the Electrode Selector (no beep when the Terrameter power is switched on).	The battery may be completely discharged in either the Electrode Selector or the Terrameter, or the communication cable between the units may be faulty.	Check that the batteries of Electrode Selector and Terrameter are properly charged, and that the cable linking the units is OK
No contact obtained at all during the contact test	Poor electrode grounding for all electrodes, or no proper response from the Terrameter	Check that the Electrode Selector is triggering and Terrameter is responding properly. If not check that all interface cables are in good condition and properly connected, and that the batteries are OK. If the Terrameter is responding check the error code, where a common reason is that the contact resistance is too high for all the electrodes. Try to improve the grounding, or step down the current (in general not recommended, will impair data quality)

⁹ A battery capacity of 60-70 Ah is recommended for heavy duty applications, i.e. continuous work for several hours with a high current setting.

Unstable and possibly negative readings	Poor electrode connection/grounding, and possibly too low measuring current. High level of self-potential.	Check that the Terrameter is set to as high measuring current as possible! If necessary water, and hammer down, electrodes, and if that is not sufficient connect two or more electrodes to each electrode take-out! Check that all connectors are in good condition and are firmly connected to the electrodes!
No contact obtained from electrode take-outs on the cable beyond the cable joint	The cable joint may be connected in the wrong direction or not connected at all	Check that the cable joints are properly connected! The groove on the cable joint should point towards the layout centre
Negative, but rather stable resistivity readings	Cable 2 and cable 3 may be switched at Electrode Selector	Check that the cables are connected to the Electrode Selector in the right order!
Unstable/unrealistic results	Badly installed electrodes. Dirty or moist connectors. Damaged spread cables.	Check that all connectors and cables are in good condition. Run CABLETST and CABLE INSULATION TEST on regular bases.

6.2.13 The ALARM Connector

The ALARM connector on the ES464 has four pins:

A	Gives 12V out at an occasion of alarm. The output is fused by 2A.
B	Pin B and C give a contact closure at an occasion of alarm. The pins are totally isolated from the rest of the system. Max permissible load would be 12V at 2A.
C	
D	0V reference

The ALARM connector on the ES10-64eC / ES10-64C has a different configuration of the four pins:

A	For 12V power supply of ES10-64eC / ES10-64C for linked units beyond the first one.
B	Gives 12V out at an occasion of alarm. The output is fused by 2A.
C	0V reference.
D	Ground for power supply.

7 TERRAMETER SAS LOG 300

This section describes the operation of the Terrameter SAS 1000 / 4000 accessories Terrameter SAS LOG 300.

7.1 CONTROLS, TERMINALS AND LOGGING CABLE

N.B. during logging operation there should be no connections to C1-C2 and P1-P2 terminals on SAS 1000 / 4000.

The SAS LOG 300 consists of a 300 m long logging cable with a logging probe and a convenient backpacking frame. On the frame is an electronic unit mounted as well as terminals for the Current Return / Potential Reference and a connector for connecting to the SAS 1000 / 4000.

The logging cable has seven nylon-insulated conductors and a polyurethane jacket. A Kevlar stress member, good for 4000N is incorporated. Three cylindrical current takeouts are located 5.6 m, 1.2 m and 0.4 m upwards from the probe shoulder. The cable is marked at 1 m intervals, starting at the logging probe shoulder.

The stainless steel upper end (shoulder) of the logging probe, serves as electrode 0 m. The lower inside end of the probe - the chamber - has one ring electrode, -0.4 m and one electrode in the centre, the chamber electrode. The centre electrode also contains the temperature transducer. The end of the chamber is set at an angle to improve circulation of fluid in the chamber as the probe moves. Three holes in the chamber wall permit air to escape, thus ensuring good contact with the fluid.

A control cable, 33 0020 11, connects the SAS LOG 300 to SAS 1000 / 4000. The SAS LOG is fully governed from the SAS 1000 / 4000.

The return current terminal is connected to a return current electrode (ABEM stainless steel electrode) placed not less than 75 m from the well to be surveyed.

The potential reference terminal is connected to a reference potential electrode (ABEM stainless steel electrode) not less than 50 m from the well and in the opposite position from the return current electrode.

Even if there is a test facility testing the ground connection for these remote electrodes, great care should be exercised when installing them to ensure reliable connection to ground.

Directly after switch on, the LOG will perform a self-check, which takes a few seconds.

The SAS LOG 300 facilitates following functional modes:

- Down (automatic measurements according to settings made in point 4 chapter 7.2, manually activated)
- Up (automatic measurements according to settings made in point 4 chapter 7.2, manually activated)
- Electrode Check
- Level Check (Water-)
- Depolarise
- Temperature
- SP Voltage
- Short Normal (Resistivity)


- Long Normal (Resistivity)
- Lateral (Resistivity)
- Fluid Resistivity (Resistivity)
- Short Normal IP
- Long Normal IP
- Lateral IP

7.2 OPERATING THE LOGGING SYSTEM

Assuming basic familiarity with SAS 1000 / 4000, these would be the steps to set up for a well logging

1. In the Application menu, select SAS LOG 300, ✓.
2. In the Record Manager Menu, define a NEW log title, ✓. (Or OPEN an old file or DELETE records,)
3. In the next menu, define the LOGGING INTERVAL in meters. This is the smallest conceivable distance between two logging points, **OK**
4. In the Log Configure menu, page 1(9), enter the distance steps for downwards and upwards logging (the logging interval is multiplied by this number, the return is the actual distance between the logging points in the respective run) and select which modes should be utilized on the way down and which on the way up, see paragraph 8.2.3, +↵-.
5. In the SP Parameter menu, page 2(9) select desired SP measuring time, +↵-.
6. In the Measure Parameter menu, page 3(9), make the desired resistivity settings, +↵-.
7. In the IP Parameter menu, page 4(9), make the desired IP measuring settings, +↵-.
8. Calibrate temperature, page 5(9), the log is shipped with default calibration values entered, which allow the stated accuracy. For special demands other values may be entered.
9. In the Stack Parameter menu, page 6(9), enter details for stacking and also whether to view apparent resistivity or resistance (plain V/I, without geometry calculations), +↵-.
10. In the Options menu, page 7(9), set options for the current transmitter, +↵-.
11. In the Info Text menu, page 8(9), make all the comments for the actual survey, +↵- or .
12. Return to the View Sample menu, page 9(9), to view retrieved data .
13. Select whether to follow the sequences preset in point 4 above, Down, or, Up, . Options are, ← / →:
 - Electrode Check, to verify whether the remote electrodes are properly installed, .
 - Level Check. Select this function and lower the probe, an indication is given on the SAS 1000/ 4000 LCD when the probe reaches the water level, .
 - Depolarise, equalizes built up potentials prior to SP measurements, .
 - Take single readings in any function mode at any arbitrary depth, .
14. The last retrieved data is shown in the upper part of the LCD, together with the relevant depth information. The next measurement and the appropriate new level according to the settings in point 4 above are suggested in the lower half of the LCD.



WARNING: Make certain that the Terrameter SAS 1000 / 4000 is turned off while handling the logging cable and probe. The cable and probe electrodes can carry high voltages after the MEASURE button  on the SAS 1000 / 4000 is activated.

7.3 TEMPERATURE & SP LOGGING

Normally temperature and SP are logged at the first run downwards the well, in the unstirred water and with no polarization effects residing from resistivity measurements.

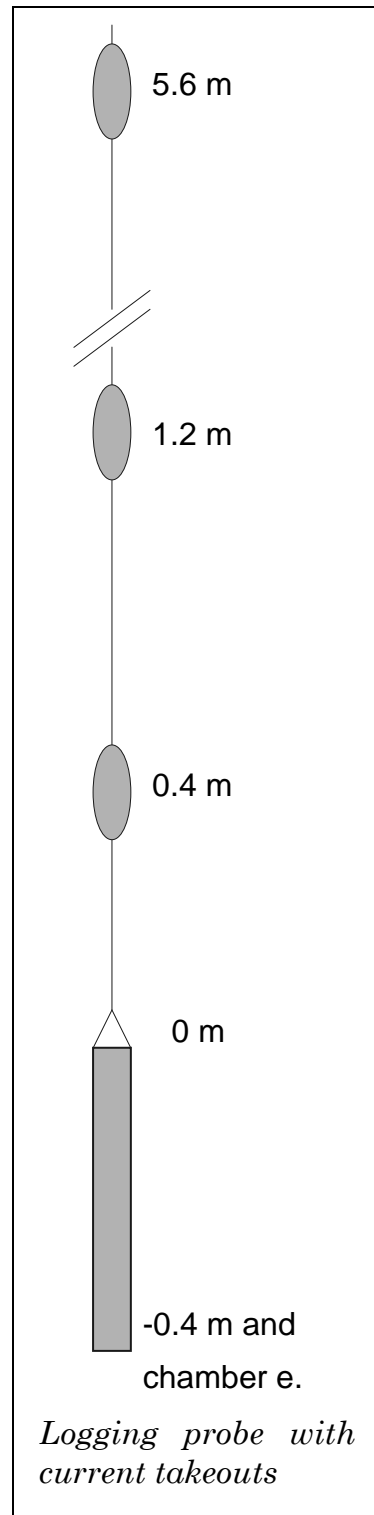
The temperature is measured to an accuracy of $\pm 1^{\circ}\text{C}$ within the $0^{\circ}\text{C} \dots +20^{\circ}\text{C}$ range and $\pm 0.1^{\circ}\text{C}$ within the $+20^{\circ}\text{C} \dots +50^{\circ}\text{C}$ range, thus permitting local temperature gradients to be studied in detail.

When assuming high precision for temperature gradient studies, ample time must be allowed to permit the probe to reach thermal equilibrium vis-à-vis the fluid. Move the probe slightly up and down a few times while waiting for equilibrium to be established. Temperature logging should be the first log at each station, since undisturbed water is required.

To reduce electrode polarization, attributable to previous resistivity measurement or long storage in air, the electrodes should be depolarised before SP logging starts.

Proceed as follows:

- Connect all cables and electrodes as explained above.
- Perform the Electrode Check.
- Select the Level Check. Lower the logging probe into the well, use the level mode to determine the depth to the water table. Return to the Info Text menu (para. 8.2.2, point 11) and enter the water table depth in the comments field.
- Lower the probe to the desired depth (i.e. as indicated in the measuring menu, 0 m for the first sample).
- Select the Depolarise and wait for this function to finish.
- Select Down.
- Press and temperature and SP will be measured, the values stored and shown in the upper half of the LCD. An imperative to proceed to next depth appears in the lower half of the LCD.
- Lower the probe to next depth as indicated on the LCD and press .
- Continue till the desired depth is reached and to where the resistivity upwards logging should commence.



The voltage that is displayed will be the potential between the remote potential reference electrode and the upper electrode, the shoulder, on the logging probe.

7.4 RESISTIVITY AND IP LOGGING

N. B. Resistivity or IP measurements should not be made during a SP logging run.

- Select Up
- Enter the actual depth in, meters, where the upwards resistivity logging should commence.
- Adjust the depth of the probe to the depth newly entered.
- Press .

All the selected “upwards” modes are now passed through one by one, followed by an imperative to hoist the probe to next level for measurement.

- Press .
- Etc.

7.5 THE RESISTIVITY AND IP MODES ARE EXPLAINED BELOW

FLUID RESISTIVITY LOGGING

The current is injected via the ring electrode, while the potential is measured between the shoulder electrode 0 m and the chamber electrode. The fluid resistivity is calculated, presented on the display, and saved in the SAS 1000 / 4000. In case of small-diameter wells a correction is needed. In table 8.1 are listed the correction factors to be used. The calculation is not done to the stored values.

<i>Well diameter in mm.</i>	<i>Correction factor</i>
50 - 60	1.08
60 - 70	1.06
80 - 90	1.03
90 - 100	1.01

Table 7-1: Correction factors used in the SAS 1000 / 4000 for small-diameter wells when measuring fluid resistivity.

SHORT NORMAL LOGGING

Current is injected via the shoulder electrode, 0 m). The corresponding response voltage is measured between the ground potential reference and the ring electrode at the bottom of the probe. The SAS 1000 / 4000 will display the resistivity of the surrounding medium.

LONG NORMAL LOGGING

Current is injected via cable electrode 1.2 m while the potential is measured at the ring electrode at the bottom of the probe. The SAS 1000 / 4000 will then display the resistivity of the surrounding medium.

LATERAL LOGGING

Current is injected via cable electrode 5.6 m, and the potential is measured between the ring electrode at the bottom of the probe and the cable electrode 0.4 m

The SAS 1000 / 4000 will automatically perform the necessary conversions, and display the resistivity of the surrounding medium, measured with the "Lateral" configuration.

7.6 FLUID RESISTIVITY AND ESTIMATION OF TDS

The SAS LOG can be used to measure the resistivity of a fluid, thus enabling you to determine the Total Dissolved Solids (TDS) in the fluid.

Resistivity is a function of water temperature, and a standard temperature (usually 25°C) must be specified for reporting resistivities or conductivities. For resistivity, the approximate conversion formulas for common standard temperatures are:

$$\rho_{18} = \rho_T (0.62 + 0.021 T)$$

$$\rho_{20} = \rho_T (0.58 + 0.021 T)$$

$$\rho_{25} = \rho_T (0.48 + 0.021 T)$$

where T is the temperature in °C in the range 5 - 50 °C and ρ_T the measured fluid resistivity at the temperature T.

Concentrations by weight

Concentrations of the common ions found in ground water are often reported by weight in parts per million (ppm). One ppm defines one part by weight of the ion to a million parts by weight of water, and it is numerically equivalent to milligrams per liter. Total dissolved solids (TDS) is also reported as ppm.

The following diagram illustrates the relationships between resistivity and TDS for various salt solutions and for an average of natural ground waters.

The TDS estimation for an average of natural ground waters is:

$$\text{TDS}_{\text{ppm}} = 6400/\rho_{25} \quad \text{where } \rho_{25} \text{ is in } \Omega\text{m.}$$

Conductance is sometimes preferred for the estimation of TDS (rather than resistance, its reciprocal) since it increases with salt content. Conductance is measured in Siemen (= S = mho = $(\Omega\text{m})^{-1}$), but for comparative purposes results are usually reported as electrical conductivity (EC) which is measured in S/m. Since most ground waters have conductivities of much less than 1 S/m (and since this method is often used to determine the TDS of ground water), it is often more convenient to use mS/m.

8 UTILITY SOFTWARE

8.1 TERRAMETER SAS4000/SAS1000 UTILITY SOFTWARE

The utility software for Windows 95/98/NT/ME/2000/XP/Vista is delivered on CD. You can also download the most recent version of the software from <http://www.abem.se>. Insert the CD in your computer, and execute the SETUP program to install the software. By default the software is installed in the directory C:\SAS4000.

Hint: If you are not comfortable with file handling, accept the default settings to avoid future path-problems.

The utility software contains several functions:

- Retrieve measured data from the Terrameter SAS 1000 / 4000
- Install new software and protocol files to the Terrameter
- Convert measured data to various file formats (e.g. for interpretation)
- Manage protocol files (e.g. for handling the LUND Imaging System)



Above is shown the main display in the Utilities software. All available commands are accessible through the toolbar. When you move the cursor over the command tools, a tool tip is displayed for information. From left to right there are: New project, Open project, Save project, Delete project or document, Program properties, Help, Get data from Terrameter, Install program module into Terrameter, Remove program module from Terrameter, Modify calibration parameters.

8.1.1 Communication between Terrameter and PC computer

The SAS 1000 / 4000 communicates with a PC compatible computer through the serial cable delivered together with the instrument.

Setting the SAS 1000 / 4000 in communication mode

In order to communicate with an external PC it is necessary to set the SAS 1000 / 4000 in communication mode. From the record manager press the **Ⓞ** key. This brings you to the Program Selection Screen which can look as illustrated to the right. Observe, that only program modules installed in the SAS 1000 / 4000 will appear in the Program Selection Screen. Move to the selection <RS232 Communication> and press **✓**. The SAS 1000 / 4000 will then be ready to

<SAS 4000 Standard> <LUND Imaging System> <RS 232 communication>
--

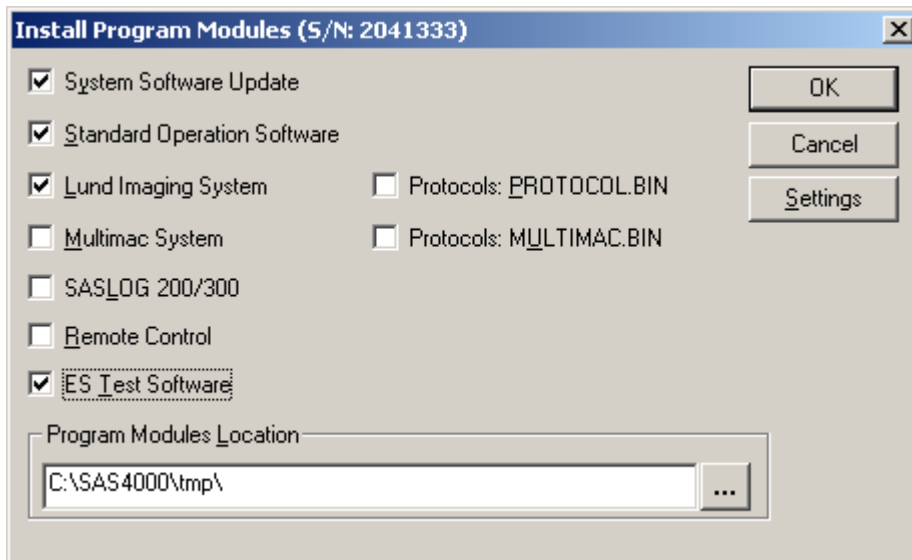
communicate with the external PC through a serial connection. Please ensure that the settings (baud rate) are identical on both the Terrameter and the computer.

VERY IMPORTANT

If you are installing (or upgrading) software to the SAS 1000 / 4000 be patient. After the necessary file(s) are copied to the SAS 1000 / 4000, the program will unpack and install itself. This procedure can take several minutes. DO NEVER TOUCH THE SAS 1000 / 4000 DURING THIS TIME. In the worst case the communication program on the SAS 1000 / 4000 will be damaged, and you have lost all possibilities to communicate with the SAS 1000 / 4000. If this happens you will need to ship the SAS 1000 / 4000 to ABEM for new program installation. Also ensure there is sufficient battery capacity before starting upgrading the communication program.

Install software on the SAS 1000 / 4000

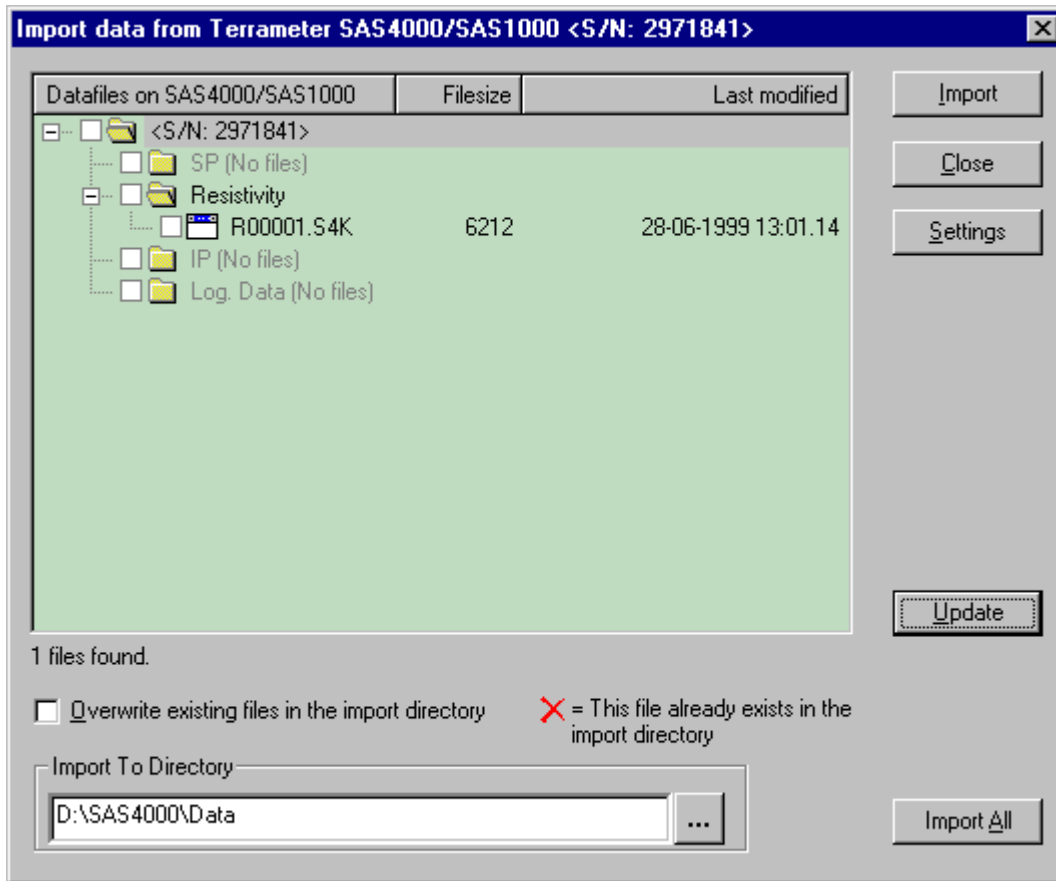
From time to time you might want to install another program module, or install an upgraded program version. In order to do this, press the appropriate toolbar (green arrow pointing downward). This brings up the “Install Program Modules” menu:



Specify which program modules you want to install, and press OK. **Please check that the serial number of your Terrameter is shown in this window. This ensures that the communication is working properly.** In case of problems with the communication, check that the baud rate is set equally on the Terrameter and on the PC. Also check that the correct serial port on the PC is used. In some rare cases it is necessary to decrease the baud rate to 19200 or 9600.

Import data from the Terrameter

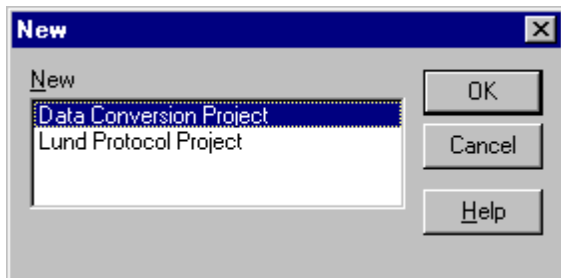
Press the toolbar (double blue arrows pointing upward) to invoke the “Import Data” menu as shown. The tree structure displays all files residing on the Terrameter. In the example shown, only one single file (named R00001.S4K) is found. You can specify exactly which files to import to the PC by marking the checkbox.



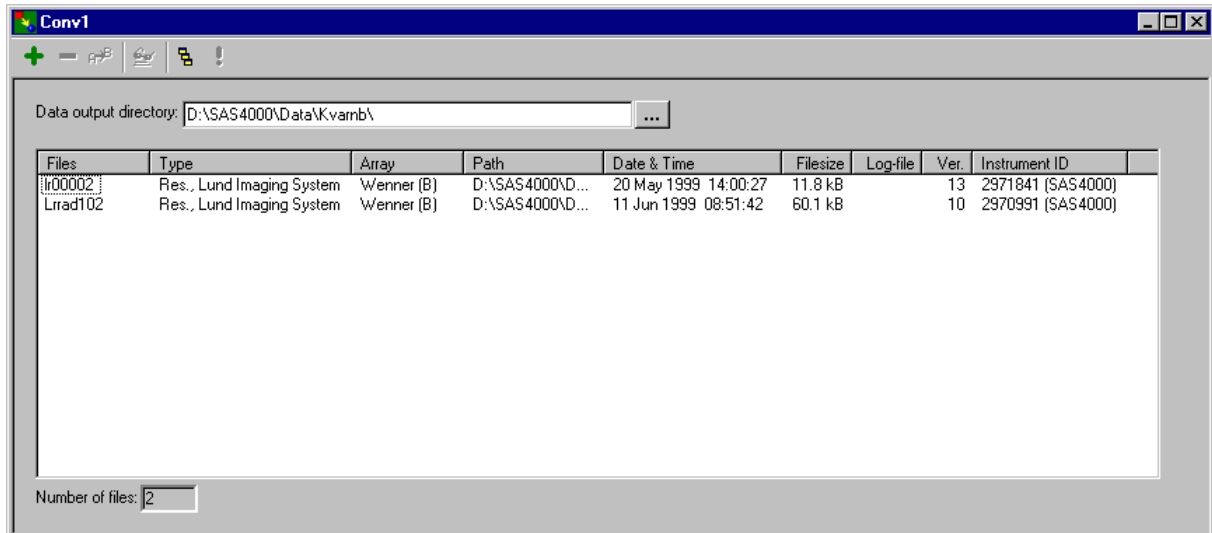
8.1.2 Data Conversion

Observe, that the files residing on the Terrameter are saved in a binary format with the file extension .S4K. It is therefore necessary to convert the data files to another convenient format. This conversion is activated in the following way:

Select the “New” toolbar. This brings up the menu

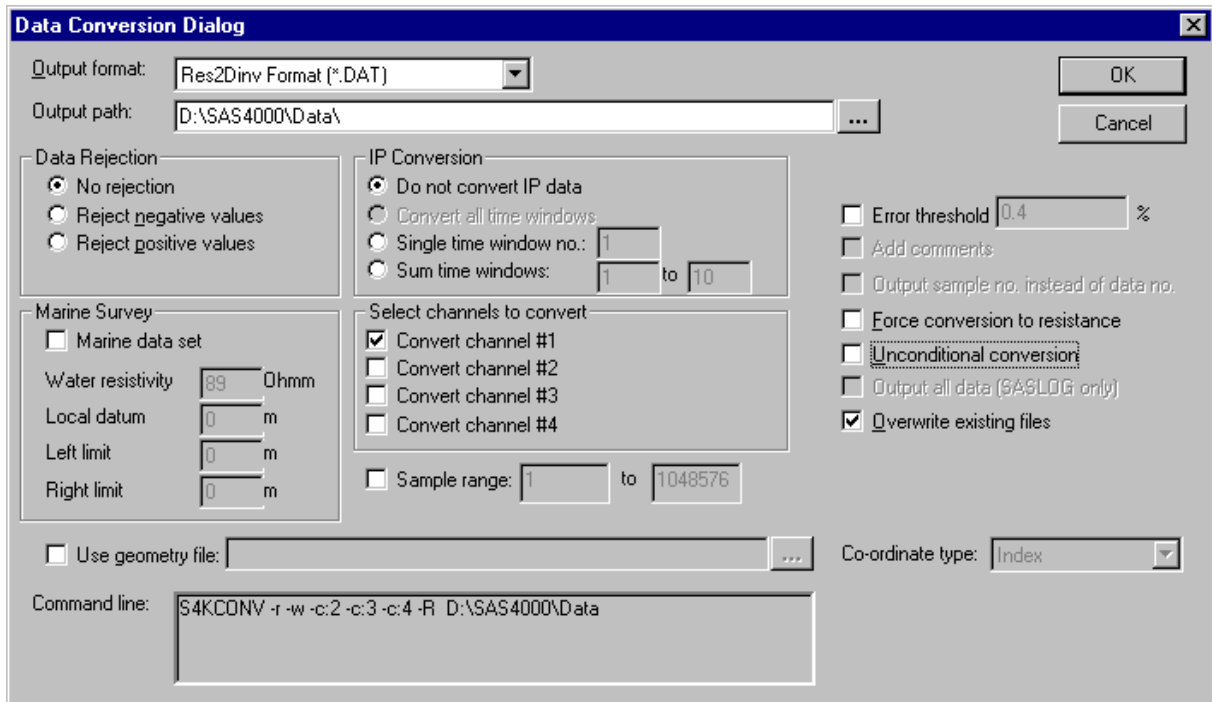


Select “Data Conversion Project” and click OK. In the conversion window, right-click with the mouse to select the data files. (Alternatively, select the menu Data Conversion – Add Files).



You can add as many files you want. Some basic information about each file is given, e.g. measuring data and instrument serial number.

To convert the files, mark them and right-click (or simply click the ! tool or press the F8 key) to convert. This brings up the Data Conversion Dialog window. Select which output format you need, e.g. RES2DINV. Most of the settings in this dialog are obvious. In fact this dialog calls an external DOS based program (called S4KCONV.EXE). In the window labelled "Command line" is shown the corresponding command line when executing the DOS based program. For more details on the DOS program, see section 8.1.3.



8.1.3 Conversion program on PC - S4Kconv.EXE

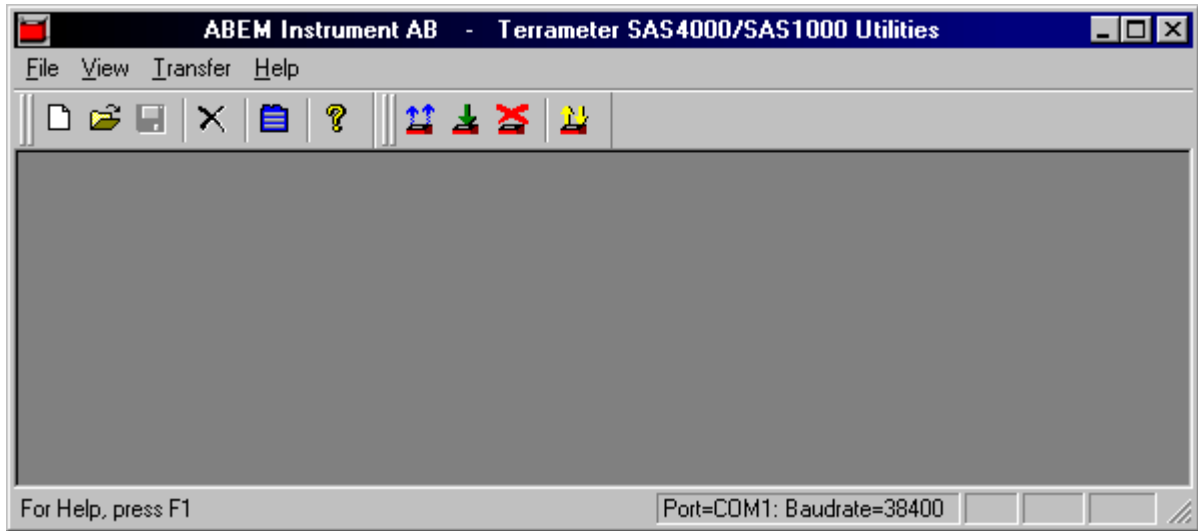
Optionally the program S4KCONV can be used to convert SAS 1000 / 4000 data, for example by typing the following on a command line:

```
S4KCONV -r LR* .S4K
```

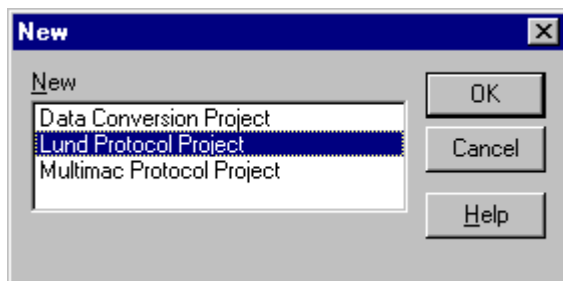
The "-r" option means conversion to RES2DINV format, which is also accepted by ERIGRAPH. In this example all LUND resistivity files are converted due to the file name LR*.S4K. (Refer to *Appendix F. S4KCONV* for information about this command.)

8.1.4 Measurement Protocol Generation and Management

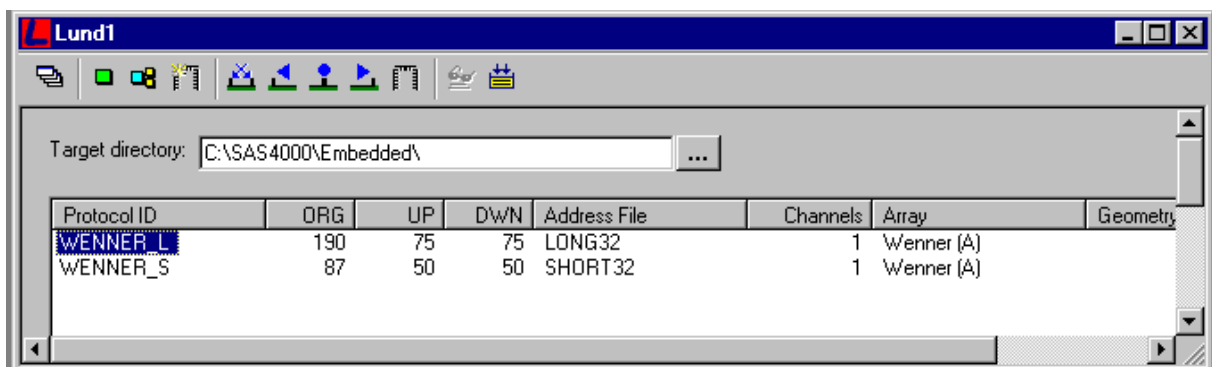
Select File, New (or use the New toolbar) in the Terrameter SAS1000/SAS4000 utility software.



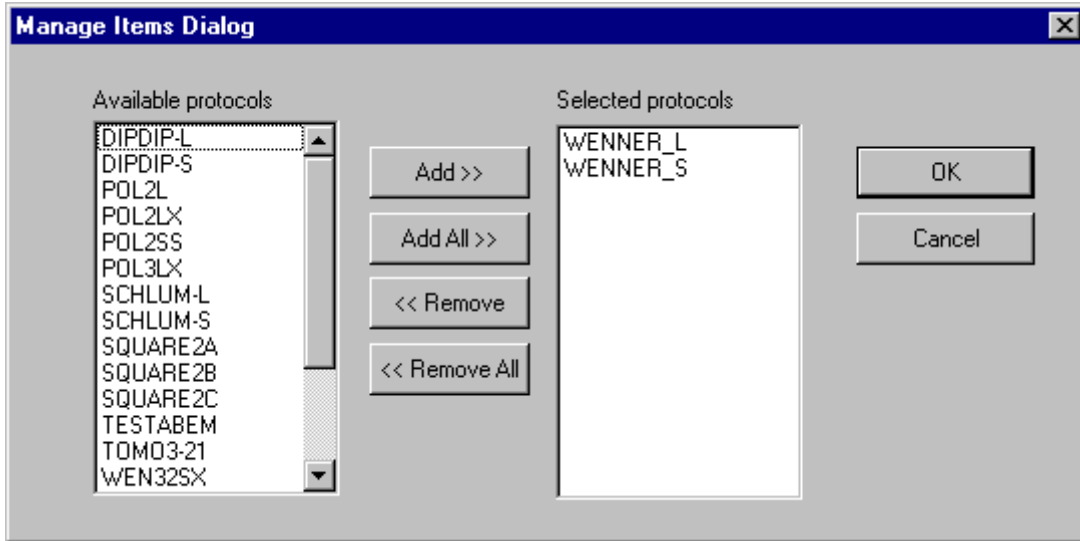
Select "Lund Protocol Project" and press OK.



The menu below appears. By moving the cursor above the different tools, a display of the function of the tool is displayed.



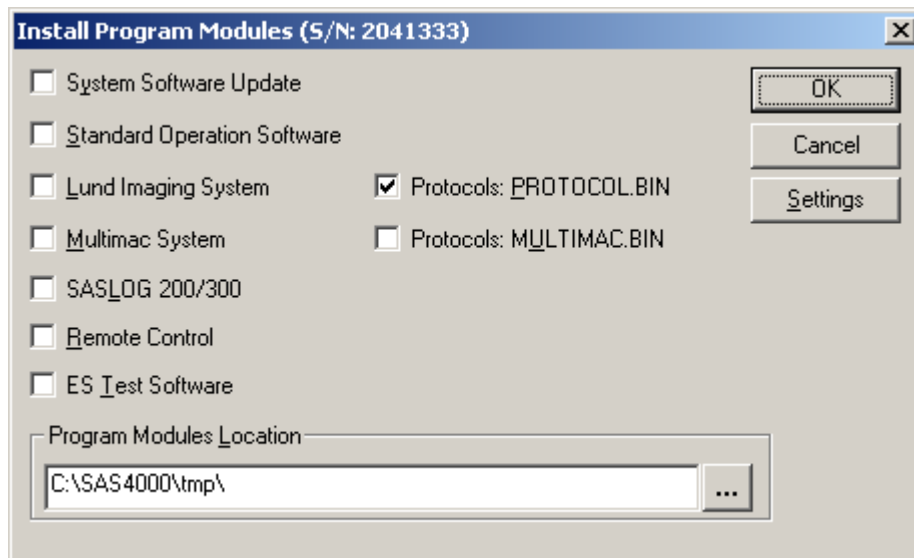
The leftmost “Manage Protocols” brings up the dialog box:



Among the available protocols (left) you can select which protocols to make active. Press OK to finish. In the above example only two protocols are selected. To compile these protocols into a binary file PROTOCOL.BIN, press the rightmost tool. This activates the Multi-electrode Protocol File Compiler (MPFC), used to compile address- and protocol-files into a binary database to be transferred to TERRAMETER SAS 1000 / 4000. Besides the fact that it is easier to handle a single database file in serial transfers it makes it possible to check that the protocol files are correct and consistent.

The program reads all address files (*.ADR) and protocol files (*.ORG, *.UP, and *.DWN) in the current directory and creates a file called PROTOCOL.BIN. When the compile is ready the resulting file PROTOCOL.BIN.

The resulting file PROTOCOL.BIN can then be uploaded into the Terrameter as described on page 53.



Error Codes in MPFC program

There are a number of error codes associated with the MPFC.EXE program, as listed in “Appendix C. MPFC Error Codes”. Errors are fatal and hence no database file will be created while warnings are non-fatal and a database file will be created.

For example, if only an ORG-file has been created and no UP- and DWN-files a warning will be issued. As it is fully legal to define only an ORG-file the compiler accepts this but warns the user that he/she might have missed to supply the UP- and DWN-files.

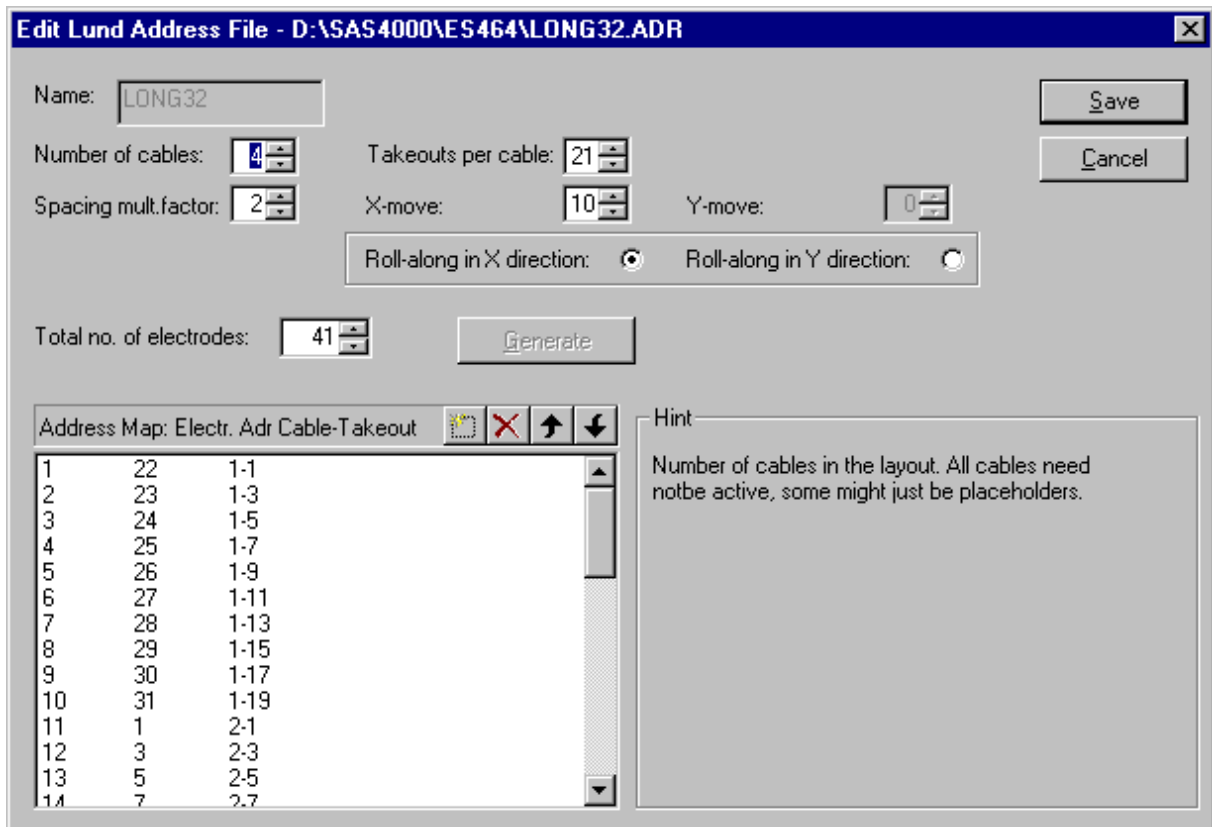
8.1.5 Format of Lund Imaging Address, Protocol and Location Files

The measurement process is controlled via address files (.ADR) and protocol files (.ORG, .UP and .DWN). For measurements involving boreholes location files (.LOC) are also used.

Cable Description Files (Address Files)

The cable description files (address files - extension .ADR) contain information about the **physical configuration of the cables** presently used: number of electrode cables, number electrode take-outs per section, internal and external addresses of electrode channels, etc. All parameters are integers.

To edit an existing address file, press the  tool. This brings up the dialog shown below.



The following format is used in the files:

- $n_{sec} n_{each}$ { number of electrode cables, total number of take-outs per cable }
- $n_{skip} n_{x-move} [n_{y-move}]$ { active electrode skip factor, lengths for x-move, lengths for y-move }
- $n_{tot} [n_x]$ { total no of active take-outs, no of take-outs in x-direction }
- 1 adr₁ cable₁-pos₁ { number, internal address and physical position of 1st take-out }
- 2 adr₂ cable₂-pos₂ { number, internal address and physical position of 2nd take-out }
- ...
- ...

ntot adr_{ntot} cable_{ntot}-pos_{ntot} { number, internal address and physical position of last take-out }

For line oriented cable arrangements with roll-along in the direction of the cable the parameters n_{y-move} and n_x are not specified, but only for areal cover and 3D cable arrangements. In these cases the parameter n_{x-move} is set to zero. Excluded electrode positions can be entered into the address file by assigning the address 0 (zero). These electrode positions will then be omitted from electrode contact test and measuring. Example address files can be found in “Appendix E. Address and Protocol Files” (page 89).

The physical connection between the multi-pole connectors and the internal relay addresses is:

<u>Connector</u>	<u>Pin Numbers</u>	<u>Internal Addresses</u>
1	1-32	1-32
2	1-32	33-64
3	1-21	54-64, 22-32

Table 8-1: The physical connection between the three ES 464 connectors and the internal relay addresses. The ES10-64 is only equipped with connector 1 and connector 2, hence an adapter is needed for connecting three cables to it.

The pins 22-32 in the standard cables are not connected to any electrode take-outs, but used for linking every second take-out on the outer electrode cables to the Electrode Selector via the cable joints. There is an overlap between the connectors, where connector three is connected to the addresses connected to pins with numbers higher than 21 in connectors one and two. This means that cable joints should not be used when a cable is connected to multi-pole connector three on the ES 464.

Protocol Files

The protocol files specify the measurement sequence, and can be designed to do measurements using arbitrary arrays.

The first station (midpoint position) is always measured using a protocol file with .ORG filename extension, whereas consecutive stations use .UP or .DWN protocol files depending on if the roll-along is done towards higher or lower coordinates. The .UP or .DWN files should normally be reduced according to the possible data overlap with the previous station, to avoid measuring the same data points twice. This also means that measuring is normally much faster for consecutive stations at a roll-along than for the first.

If more than one protocol file is used for each station there is also a possible overlap, between the protocol files at the same midpoint, as for example when doing Wenner CVES with long and short layouts. In this case one of the files should be reduced accordingly.

The protocol files contain an array code, the address file used followed by a comment string, and the logical positions of the electrodes. The positions are given for the current electrodes followed by the position of the potential electrodes. The format is thus:

```
code           [arraystring]
addressfile    [commentstring]
Apos(1) Bpos(1) Mpos(1) Npos(1)
Apos(2) Bpos(2) Mpos(2) Npos(2)
...
Apos(n) Bpos(n) Mpos(n) Npos(n)
```


where the electrode positions are given as integers in the interval $1-n_{tot}$. If remote electrodes are used these positions are specified as zero. Example protocol files can be found in “Example Protocol Files” (page 91).

The array codes are used mainly for presentation purposes, and in the case of pole-pole and pole-dipole how the contact test is performed. The following codes are defined:

<u>Code</u>	<u>Array</u>
0	Resistance
1	Wenner- α
2	Wenner- β
3	Wenner- γ
4	Pole-Pole
5	Dipole-dipole
6	Pole-dipole
7	Square- α
8	Square- β
9	Square- γ
10	Schlumberger
11	General surface array
12	Tomography
13	Equatorial dipole-dipole
15	Multiple gradient array

If an array not defined in the list is to be used, array code 0 may be used, which means that resistance instead of apparent resistivity is displayed during measurement. If array code 12 is used only the electrode numbers, and not the coordinates are saved, which is suitable for e.g. measurements involving boreholes (see section on geometry files below).

Geometry Files

The electrode coordinates for a borehole measurement are entered via a geometry file (textfile with XYZ file extension), with the following format:

```

n-cables
Header cable 1
1      x1,1    y1,1    z1,1
2      x1,2    y1,2    z1,2
...
n1    x1,n1   y1,n1   z1,n1
Header cable 2
1      x2,1    y2,1    z2,1
2      x2,2    y2,2    z2,2
...
n2    x2,n2   y2,n2   z2,n2
Header cable 3
1      x3,1    y3,1    z3,1
2      x3,2    y3,2    z3,2
...
n3    x3,n3   y3,n3   z3,n3

```

An example is given in “Appendix E. Address and Protocol Files”.

8.1.6 Format of VES Protocol Files

The electrode geometry for VES can be pre-defined via measurement protocols defined via a textfile saved with XYZ file extension (the filename must have maximum 8 characters). The file can be prepared in a suitable spreadsheet or text editor, and should have the following format:

```

No of variables
Comment label 1
1      data 1,1
2      data 1,2
...
n1    data 1, n1
Comment label 2
1      data 2,1
2      data 2,2
...
n2    data 2,n2

```

The following example shows a VES protocol for a Schlumberger sounding, where the current electrode spacings are listed first followed by the potential electrode spacings:

```

2
Comment AB/2
1      1
2      1.4
3      2.2
4      3.2
5      4.6
6      6.8
7      10
8      14
9      22
10     32
11     46
12     68
13     100
14     140
15     220
16     320
17     460
18     680
19     1000
Comment MN/2
1      0.2
2      0.5
3      2.0
4      5.0
5      20
6      50

```

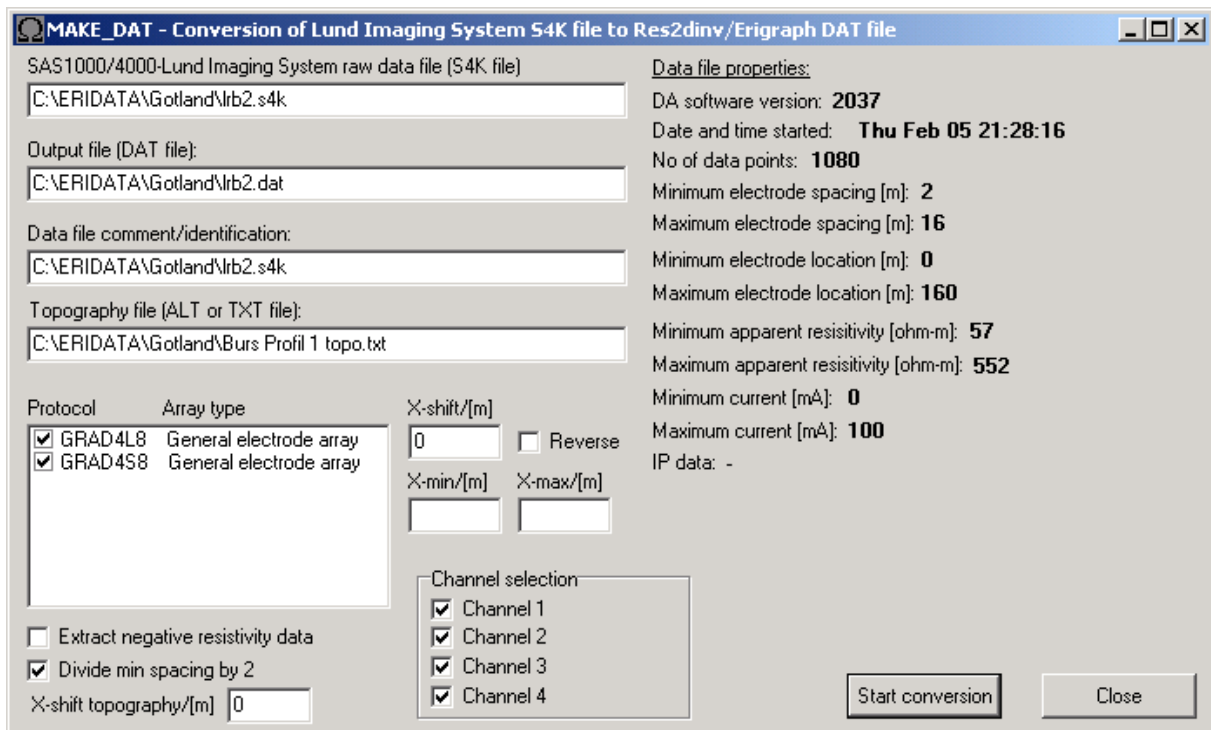
The file is uploaded to the Terrameter using the function “Transfer/Install XYZ file”.

8.2 ERIGRAPH

The software ERIGRAPH is primarily designed to facilitate graphical presentation of CVES (2D electrical imaging) data and associated inverted model sections. The measured apparent resistivity can be plotted as pseudosections in colour or grey scale. Inverted sections can be plotted as continuous (smooth) plots or as rectangular blocks. 2D inversion must be carried out using a separate inversion program, such as for example Res2dinv. Conversion from the field data files formats OHM¹⁰ and S4K to DAT format is also built-in, as well as conversion to model files in RHO format from the output formats INV and XYZ created by RES2DINV.

8.2.1 Data Conversion

Before displaying the field data must be converted to the DAT format used by RES2DINV. By selecting File/Conversion/S4K->DAT in ERIGRAPH the menu below will appear, and upon selecting a data file the data file properties will be summarised. By ticking on/off protocols and channels different sub-sets of the data can be extracted, and it is also possible to shift or reverse the length coordinates.



The built-in conversion routine in ERIGRAPH can automatically incorporate topography in the DAT file, if it is saved in an ASCII file (preferably in the same directory as the OHM file to be converted). The topography file should have the same filename as the data but with ALT or TXT extension. The file format is as follows:

```

x(1)                                alt(1)
x(2)                                alt(2)
...
...
x(n) alt(n)
    
```

¹⁰ Used by ERIC.EXE for data acquisition controlling Terrameter SAS300C and Electrode Selector ES464 from a PC.

If the topography is not included in the DAT file by the conversion routine it can be manually copied into the data file in the regular format after the resistivity data, but a line with the text "Topography in separate list" must be added between the resistivity data and the topography data (i.e. immediately before the topography data section) when using the general four electrode format.

8.2.2 Pseudosection Plotting

A common method for qualitative presentation of CVES/2D resistivity data is the drawing of pseudosections. A pseudosection is made by plotting the data points in a diagram, using the length axis for the distance along the surveying line and the depth axis for the electrode separations, as indicated in Figure 17.

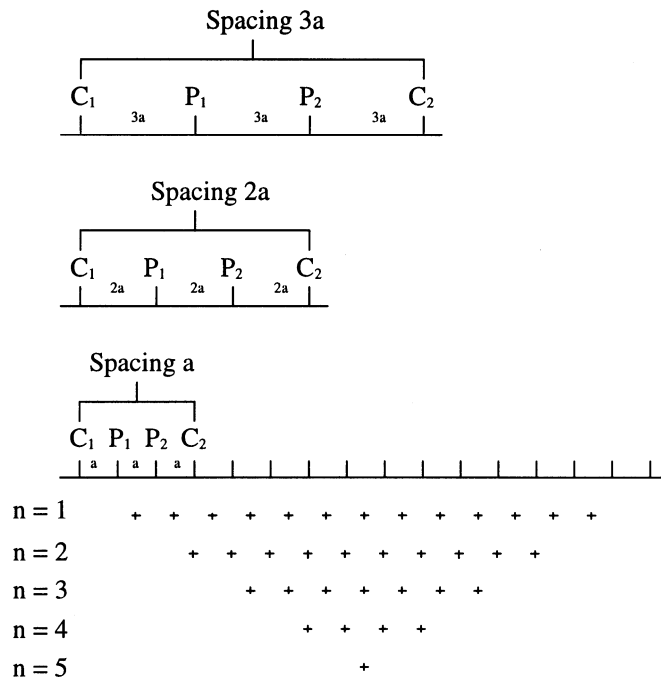


Figure 17. Principle for building up a pseudosection

The distance for the electrode configuration midpoint is thus plotted against the electrode separation for each measured data point, letting the latter reflect the measurement depth. The corresponding apparent resistivity for the plotted points are then used to contour the variation in apparent resistivity along the surveying line. The pseudosection thus obtained reflects the variation of resistivity in the ground in a qualitative way, and an experienced interpreter may estimate approximate structures and depths to layer interfaces. It should be noted that a pseudosection is simply a 2D equivalent of the plotted field data points in a VES diagram, however normally with a linear depth scale instead of a logarithmic scale as is normally used in VES.

In this context, the drawing of pseudosections needs computer assistance to be practical due to the large amounts of data. The ERIGRAPH software is developed for automatic drawing of pseudosections in grey scales or colour, using linear interpolation between data points. Linear interpolation involves no smoothing of data, which gives a good indication on the data quality.

The selection of resistivity interval limits is of major importance when presenting data, as the perception of the plotted data is strongly controlled by the colours. A suitable selection of limits may enhance the geological variation, while an unsuitable selection may hide important information or enhance irrelevant features. Obviously it may be necessary to have geological reference for optimising the data presentation. The character of resistivity data often makes it suitable to use a logarithmic distribution between the resistivity intervals.

The example of a pseudosection plot in Figure 18 shows the response of a vertical contact, with 10 Ωm to the left of the contact and 100 Ωm to the right. The example shows analytically calculated model response (Carpenter, 1955), and emulates data sampled in a pattern similar to that of the data collection system. The example points out the importance of being aware of the strong lateral effects on DC-resistivity data of vertical discontinuities when interpreting pseudosections, and the necessity of using inverse modelling (inversion) to get an image that reflects the true geometry of the investigated object.

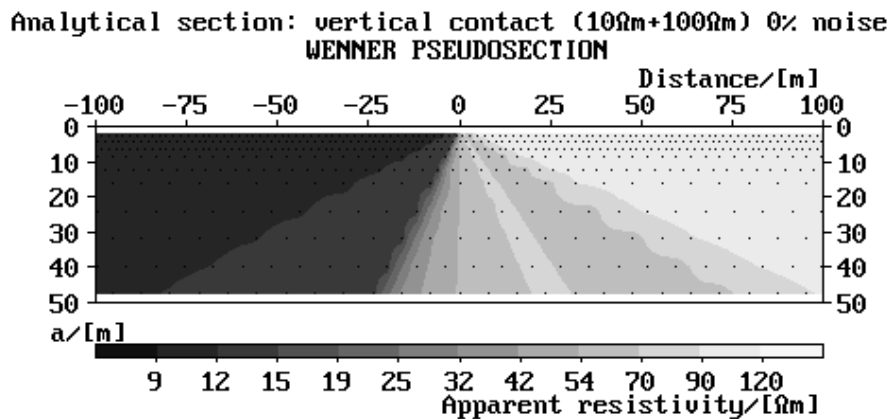
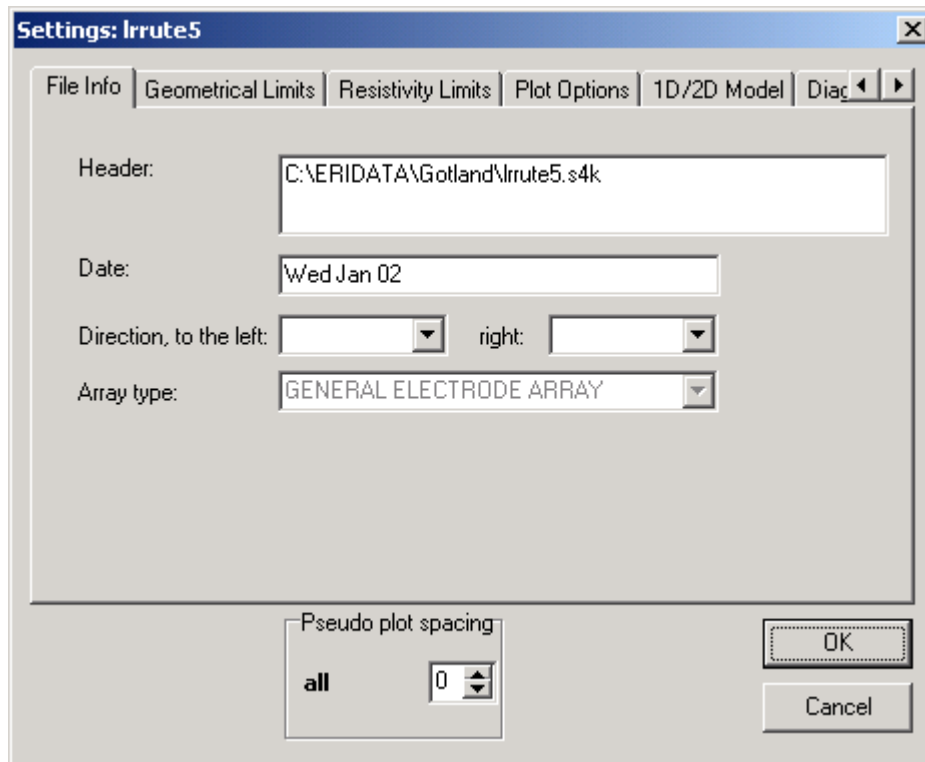


Figure 18. Example of a Wenner pseudosection plot showing analytical response of a single vertical contact (10 Ωm and 100 Ωm), with data sampled as field data.

The software was developed for plotting of DC-resistivity data measured with a multi-electrode array, implying that electrode spacing are always an integer multiple of the smallest electrode spacing used. Furthermore, profile distance coordinates are assumed to fall into the same positions as data for the smallest electrode spacing or halfway between them. If data stored in another geometrical pattern is plotted with the program it may not function properly.

To view the converted data file as a pseudosection run ERIGRAPH and select open data file. By clicking the “Edit diagram settings” icon, or by right click on the diagram window, the settings menu below will appear with various plot options.



8.2.3 2D and 3D Model Interpretation

Model interpretation accounting for 2D or 3D variation is not supplied with the system, but third party software packages for resistivity data processing can be used for advanced interpretation. Two such examples of programs are RES2DINV, SENS2DINV and RESIX 2DI, which perform smoothness-constrained inversion (inverse modelling). Please ask ABEM or your authorised ABEM Distributor for details about resistivity interpretation packages that are available.

For inverting the data with RES2DINV transfer the S4K files to a computer in the regular way via the SAS1000/4000 Utility Software or use ERIGRAPH (version 2.9 or higher) for the conversion¹¹. The latter will by default specify half the actual minimum electrode separation on the second line of the data file for some electrode arrays (e.g. multiple gradient array, dipole-dipole, pole-dipole), which forces RES2DINV to use a finer grid in the inversion model. This is recommended as the inversion routine can have difficulties in handling the increased information content in the data, compared to e.g. Wenner array data, which may create artefacts if a coarser grid is used. Data is saved in the general four electrode format i.e. array code 11, and sub-array code 0 (unspecified array) 15 (gradient array), 3 (dipole-dipole) or 6 (pole-dipole).

Figure 19 shows an example plot of a 2D model interpretation section, inverted using RES2DINV. Before plotting by ERIGRAPH it is necessary to convert from the iNV format to RHO format, which can be done either in RES2DINV or ERIGRAPH. In cases with steep topography the inverted model files from RES2DINV often benefit from converting to RHO format from an XYZ file exported from RES2DINV, rather than converting directly from the INV file. In order to include topography into the exported XYZ file it is necessary to plot the model section including topography before exporting.

¹¹ At present there is a maximum of 6000 data points in the conversion routine.

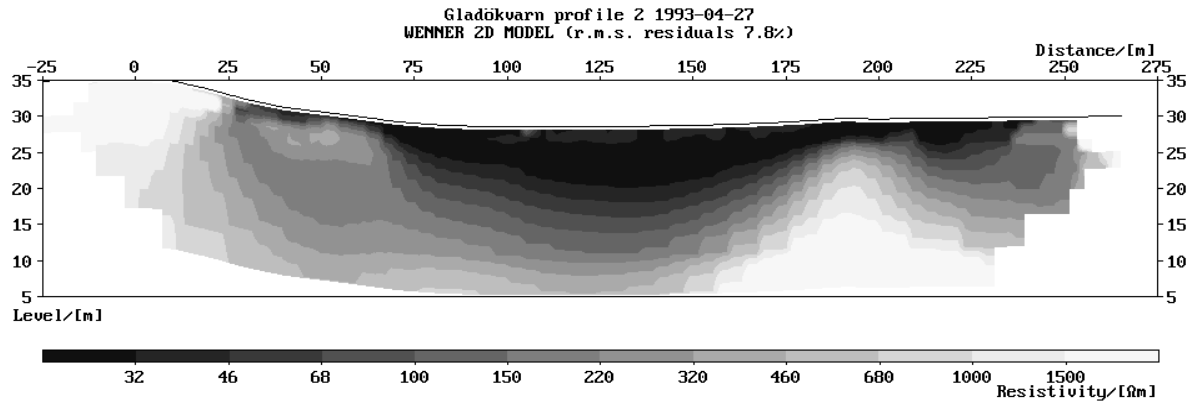


Figure 19. Example of an inverted 2D section.

8.2.4 Data Quality Checking and Editing

ERIGRAPH can be used for a visual data quality assessment, and it is recommended to plot data for each n-factor or each electrode spacing separately, or it may appear as the example in Figure 20. Furthermore, since many data points may be overlapping in the plots, the function to plot either the first or the last data point saved in the data file should be used.

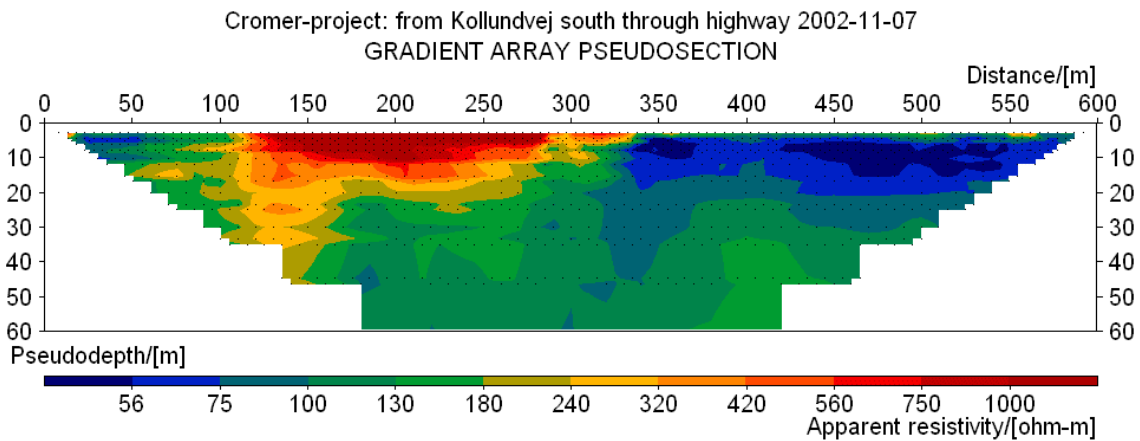


Figure 20. Example of pseudosection plot of multiple gradient array data with mixed n-factors and electrode separations.

It is possible to use the “Exterminate bad datum points” feature in RES2DINV¹² for editing away noisy data points. It is, however, often more difficult to identify which are the noisy data points for arrays with a mix of different a-separations and n-factors than for e.g. Wenner data. It is common that the plots have an apparently noisy character even for very good data quality. However, from version 3.55 RES2DINV has a facility to plot multiple gradient array data in a way that facilitates editing, provided sub-array type 15 is specified on line 3 in the DAT-file, see example in Figure 21.

¹² Res2dinv version 3.51 or later of is assumed.

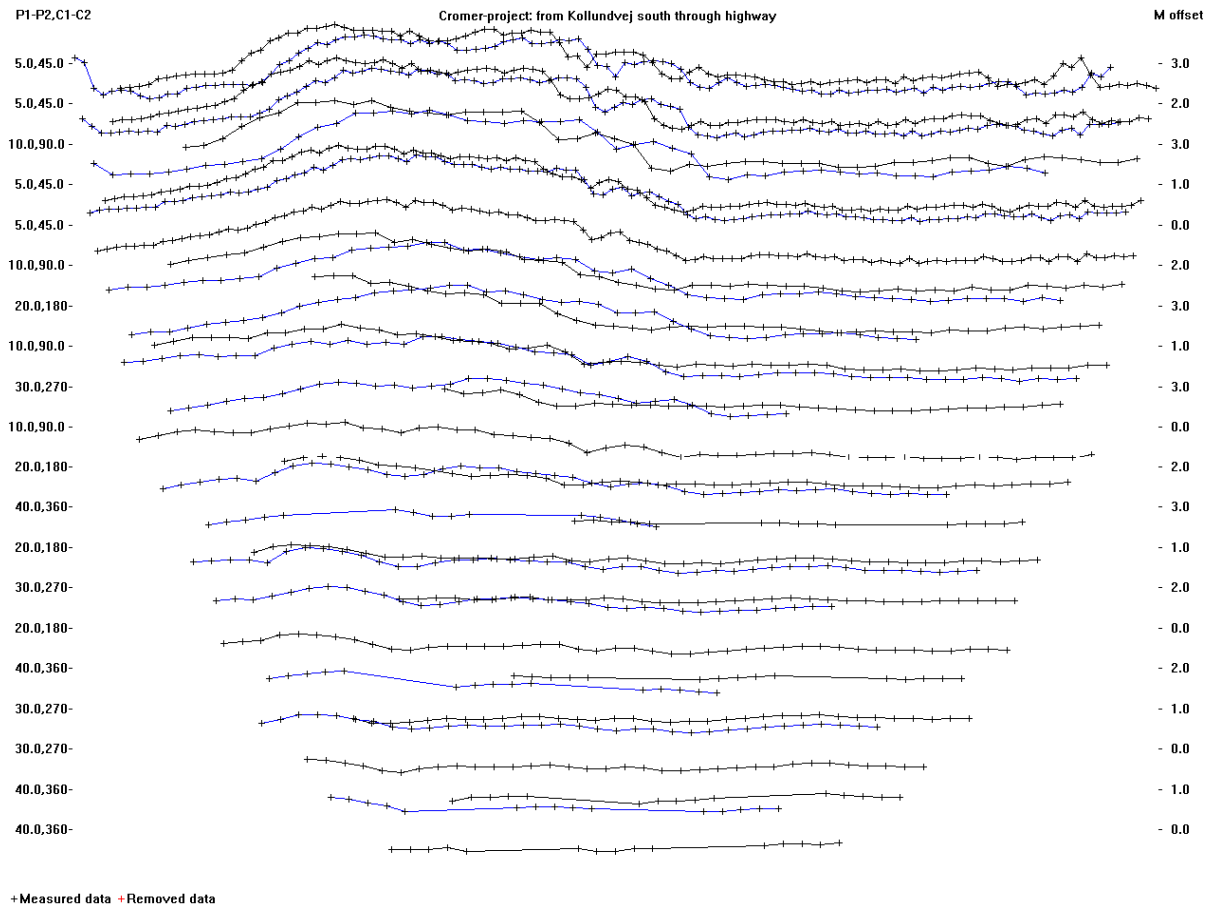


Figure 21. Example of RES2DINV “Edit bad data” plot of multiple gradient array data.

Another way to deal with data quality is to start running a preliminary inversion using the robust inversion method. The function “Display/Edit data/Estimate data errors” can then be used to save the data with estimates of the measurement errors, which are based on the model residuals from the inversion. The thus created file is used for running the inversion once more. In cases with noisy data this can create more realistic inverted models.

9 SERVICING THE EQUIPMENT

The Terrameter SAS System is designed to withstand the normal wear and tear encountered in field work.

9.1 GENERAL PRECAUTIONS

Excessive vibration, temperature and moisture exposure should be avoided:

- Do not transport the instrument loose on vehicle floors or truck beds.
- Avoid excessive temperature exposure such as direct sunshine in hot weather.
- Do not expose the instrument to rain for long periods. It is splash proof but not submersion proof.

9.2 DATA STORAGE MEMORY

The number of readings that can be stored in the internally depends on the size of the internal disk. Due to the construction of the storage medium, the read- and write-procedures now and then takes longer time than usual, i.e. several seconds for some instrument generations. This is due to an internal algorithm that "spreads" the data on the disk.

It is recommended not to fill the data memory to 100 percent.

Important:

A good advice is now and then to go to the <Setup> menu and select the command <Disk Cleanup>.

9.3 ERROR CODES

Whenever an error occurs in the SAS 1000 / 4000 a code is displayed on the screen. The meaning of the codes is explained in “Appendix B. Terrameter error codes” (page 82).

9.4 STORAGE AND HUMIDITY

When not in use, instruments should be stored in dry premises.

If the instrument has been exposed to excessive humidity during a long period, lifting the circuitry out of the case and letting it dry in the sun or near a stove can dry it. Remember, however, that static electricity can damage the circuitry.

IMPORTANT

Static electricity can damage the components in the circuitry. Do not touch any circuitry needlessly with your hands or your tools. Always discharge yourself by touching a grounded object before handling the internal parts of the SAS 1000 / 4000. Protect your workshop against static electricity.

9.5 PERIODIC CHECKS

9.5.1 Terrameter SAS 4000 - Check

The proper functioning of most of the SAS 4000 circuitry can be checked using reference resistors and a capacitor having known values. This test should be performed at least once per year.

Two resistors and one capacitor are built into the Multi Channel Adapter (optional accessory 33 0020 02). Their nominal values are:

Between terminals:	Resistance:	Capacitance:
T1 and T2	1 Ω	no
T3 and T4	15 k Ω	1 μ F
T2 and T4	15 Ω	no

The following procedure will check the SAS 4000 and also check the values of the above components. Enter the readings in the table below.

To perform the test, proceed as follows:

1. Connect P1 (from e.g. CH1) to T3 using a fork connector underneath the knob on T3
2. Connect P2 (from e.g. CH1) to T4 using a fork connector underneath the knob on T4
3. Connect C1 to T3 and C2 to T4 using the banana connectors
4. Perform a resistivity measurement using AUTO output current and enter the reading in the table below
5. Perform a IP measurement using AUTO output current (one time window, from 10 msec to 110 msec) and enter the reading in the table below
6. Repeat step 1-4, but with the cables connected to T1 and T2.
7. As in 6, but with cables connected to T2 and T4.
8. Move the banana connectors from CH1 to CH2 (and after that to CH3 and CH4) and repeat step 1-7

Write down the measured values in this table for future reference:

		CH1	CH2	CH3	CH4	Expected	
T3 - T4, resistivity	R =					≈15	kΩ
T3 - T4, IP	M _{10,110} =					≈7.7	msec
T1 - T2, resistivity	R =					≈1	Ω
T2 - T4, resistivity	R =					≈15	Ω

Deviations from the expected values of up to 10% are acceptable, because the components only have a limited accuracy. Usually the chargeability reading M_{10,110} is in the range 8.0 to 8.5 msec.

If in future checks, minor changes in the readings occur (within, say, 1%) they can be attributed to temperature changes etc.

9.5.2 Quick check of SAS 1000 / 4000

During field work it happens that “it just does not work”. It will be necessary to quickly sort the problem out.

A very quick check of SAS 1000 /4000 is done in a few steps:

- With the unit switched On and set for resistivity, No cables (but the power cable) attached. Preferably the unit should be set to show ohms instead of ohmmeters.
- Press the red MEASURE button
- ERROR 1 should appear on the LCD, this is a sign of health.
- Attach a piece of metal wire, a straightened paper clip or so under the terminal nuts C1 and C2. The piece of metal might be replaced by a resistor with a known value and so the test will also be a simple quality check.
- Attach a piece of wire between C1 and P1, likewise between C2 and P2 Again straightened paper clips serve well.
- Press the red MEASURE button.
- ERROR 1 should not appear. If a reasonable low reading, some 10 to 100 mΩ or a value corresponding to the resistor used appears, there are reasons to assume the unit under test is in shape.
- The test may be repeated with other current settings, different resistors etc.

9.6 TESTING OF LUND EQUIPMENT

9.6.1 Fast continuity test of cable and relay switch



Figure 22. Connecting both ends of one LUND cable to the ES464 / ES10-64eC / ES10-64C.

It is possible to test each of the 32 conductors in a LUND cable by use of the ordinary LUND program module, using a special protocol file.

1. Connect both ends of one LUND cable to connector 1 and 2 on the ES464 / ES10-64eC / ES10-64C as illustrated in the above figure.
2. Connect the SAS 1000 / 4000 to the ES464 / ES10-64eC / ES10-64C as usual and turn on the equipment.
3. Start the “LUND Imaging System”, select Resistivity Mode and define a record.
4. Select the protocol denoted “CABLETST”. If this protocol is not loaded in the instrument, please compile a new PROTOCOL.BIN (containing this protocol) using the SAS 4000 Utility Software and download it into the SAS 1000 / 4000.
5. Select the current 1000 mA, and Acq. delay and Acq. time = 0.1 sec. Select stacks=1 and NO electrode test.
6. Press MEASURE to start the measuring sequence.
7. During the measuring sequence, the display will show the resistance in Ohm of each conductor.

8. The resulting .S4K file can be converted to an AMP file for documentation. An example of such an .AMP file is shown below.

```

Filename:          D:\SAS 4000\Data\lrtest02.s4k
Instrument ID:     SAS 1000  2001336
Date & Time:      16/08/2000 09:57:07
Base station:     0.00    0.00    0.00    0.00    0.00
Rows header/data/topography: 27    32    0
Acquisition mode: 2R
Measurement method: Section
Electrode layout: 0    Resistance RES
Co-ordinate type: Index
Smallest electrode spacing: 1.00
Marine survey (R,h,a,b): -    -    -    -
Protocol #1:      CABLETST
Protocol #2:      -
Protocol #3:      -
Protocol #4:      -
Protocol #5:      -
Protocol #6:      -
Protocol #7:      -
Protocol #8:      -
Operator:
Client:
Comment #1:
Comment #2:
Comment #3:
Comment #4:

```

No.	Time	Tx	Rx	Dx	I(mA)	Voltage(V)	Res.(ohm)	Error(%)	
1	37	nan	nan	nan	1000	22.277361	22.277361	nan	
2	45	nan	nan	nan	1000	21.702435	21.702435	nan	
.....									
29	299	nan	nan	nan	1000	10.687839	10.687839	nan	
30	308	nan	nan	nan	1000	10.770562	10.770562	nan	
31	316	nan	nan	nan	1000	10.733336	10.733336	nan	
32	326	nan	nan	nan	1000	10.993915	10.993915	nan	

The whole procedure takes typically 5-6 minutes. In the above example, some of the conductors have resistance values around 22 Ohm, and some around 11 Ohm. This is because of the fact that some conductors are connected in parallel, thus causing lower resistance readings.

9.6.2 Special checks in the module “Test Software”

Check Cable Isolation.

Will check the cable spread for short circuit or leakage. Only one end of the cables should be connected to the ES464, ES10-64eC or ES10-64C, and all takeouts must be isolated from the ground. If using the two white Cable Joints, the outer two cables will only be partially tested. To overcome this, run the test in two rounds with two cables each time. Alternatively replace the white joints with electrically transparent (black) Cable Joints, part number 33 0019 35.

Auto Relay Test

Will set and reset every relay of the ES464. No cables should be connected. This is a lengthy procedure, takes like 30 minutes.

Manual Relay Switching

Allows the user to set or reset any individual relay in the switch box. Useful for testing a specific address (e.g. set an address and check for continuity with a digital multimeter) or for taking a single reading in a cable spread.

9.6.3 Terrameter SAS LOG 300 - Checks

A full check of the SAS LOG 300 is quite complicated and must be done in the ABEM laboratory. However, the thermometer and the fluid resistivity cell can be checked fairly accurately using a fluid of known temperature and resistivity in a suitable container. Currently ABEM advises against altering the factory set parameters for thermometer function.

To test the fluid resistivity cell, the entire logging probe must be submerged well below the fluid surface. The return current terminal and the potential reference terminal must be well separated from each other and also from the logging probe.

10 APPENDIX A. BASIC PRINCIPLES OF RESISTIVITY SURVEYING

10.1 GENERAL

The SAS 1000 / 4000 measures different parameters that characterizes the ground:

- Resistivity
- Induced Polarization
- Self Potential

The electrical resistivity varies between different geological materials, dependent mainly on variations in water contents and dissolved ions in the water. Resistivity investigations can thus be used to identify zones with different electrical properties, which can then be referred to different geological strata. Resistivity is also called specific resistance, which is the inverse of conductivity or specific conductance. A very brief introduction to resistivity surveying is given below, for further information the reader is referred to textbooks on the subject (e.g. Parasnis 1997; Reynolds 1997; Sharma 1997; Telford et al. 1990; Ward 1989).

A brief section introducing multiple gradient array surveying is also included since it is not described in the textbooks mentioned above.

10.1.1 Resistivity of Natural Materials

The most common minerals forming soils and rocks have very high resistivity in a dry condition, and the resistivity of soils and rocks is therefore normally a function of the amount and quality of water in pore spaces and fractures. The degree of connection between the cavities is also important. Consequently, the resistivity of a type of soil or rock may vary widely, as shown in Figure 23. However, the variation may be more limited within a confined geological area, and variations in resistivity within a certain soil or rock type will reflect variations in physical properties. For example: the lowest resistivities encountered for sandstones and limestones mean that the pore spaces in the rock are saturated with water, whereas the highest values represent strongly consolidated sedimentary rock or dry rock above the groundwater surface. Sand, gravel and sedimentary rock may also have very low resistivities, provided the pore spaces are saturated with saline water, which is not indicated in Figure 23. Fresh crystalline rock is highly resistive, apart from certain ore minerals, but weathering commonly produces highly conductive clay-rich saprolite. The variations in characteristics within one type of geological material makes it necessary to calibrate resistivity data against geological documentation, from for example surface mapping, test pits or drilling. However, this applies to all geophysical methods.

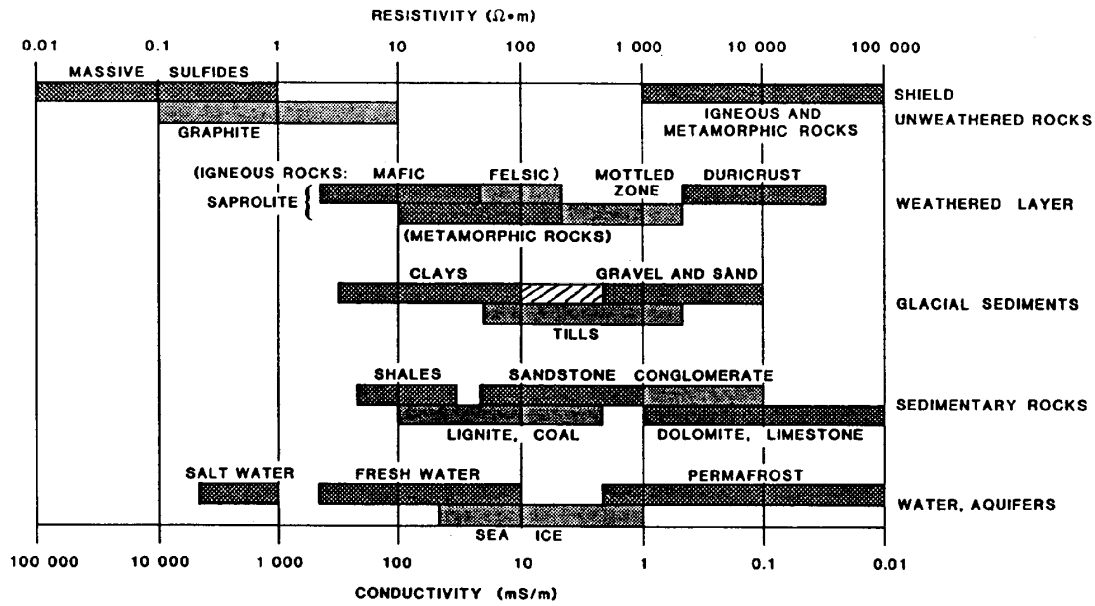


Figure 23. Typical ranges of electric resistivities of geological materials.

The amount of water in a material depends on the porosity, which may be divided into primary and secondary porosity. Primary porosity consists of pore spaces between the mineral particles, and occurs in soils and sedimentary rocks. Secondary porosity consists of fractures and weathered zones, and this is the most important porosity in crystalline rock such as granite and gneiss. Secondary porosity may also be important in certain sedimentary rocks, such as limestone. Even if the porosity is rather low, the electrical conduction taking place through water filled pore spaces may reduce the resistivity of the material drastically. The degree of water saturation will of course affect the resistivity, and the resistivity above the groundwater level will be higher than below if the material is the same. Consequently, the method can be used for finding the depth to groundwater in materials where a distinct groundwater table exists. However, if the content of fine grained material is significant the water content above the groundwater surface, held by hygroscopic and capillary forces, may be large enough to dominate the electrical behaviour of the material.

The resistivity of the pore water is determined by the concentration of ions in solution, the type of ions and the temperature. A range of resistivities for different types of water is given in table 10-1 below.

Type of water	Resistivity [Ωm]
Precipitation	30 - 1000
Surface water, in areas of igneous rock	30 - 500
Surface water, in areas of sedimentary rock	10 - 100
Groundwater, in areas of igneous rock	30 - 150
Groundwater, in areas of sedimentary rock	> 1
Sea water	≈ 0.2
Drinking water (max. salt content 0,25%)	> 1.8
Water for irrigation and stock watering (max. salt content 0,25%)	> 0.65

Table 10-1. Electric resistivity of some types of natural waters

The presence of clay minerals strongly affects the resistivity of sediments and weathered rock. The clay minerals may be regarded as electrically conductive particles, which can absorb and release ions and water molecules on its surface through an ion exchange process.

As the variation in temperature of the ground is generally small, the temperature influence is normally negligible. However, in e.g. geothermal applications the variation can be significant, as well as in permafrost regions. The mobility of ions increases with increasing temperature, as the viscosity of water is lowered. Hence a decrease in resistivity with increasing temperature can be observed for materials where electrolytic conduction dominate.

10.1.2 Measurement Principles

Measurement of the resistivity of the ground is carried out by transmitting a controlled current (I) between two electrodes pushed into the ground, while measuring the potential (U) between two other electrodes. Direct current (DC) or an alternating current (AC) of very low frequency is used, and the method is often called DC-resistivity. The resistance (R) is calculated using Ohm's law:

$$R = \frac{U}{I} \tag{A.1}$$

The material parameter resistivity (ρ), which is the inverse of electrical conductivity (σ), is related to the resistance via a geometrical factor. It is common, but not necessary, to place the potential electrodes symmetrically spaced on the line between the current electrodes. The resistivity of ground can be calculated using:

$$\rho = K \frac{U}{I}$$

where the geometrical factor is

$$K = 2\pi \left[\frac{1}{r_{11}} - \frac{1}{r_{12}} - \frac{1}{r_{21}} + \frac{1}{r_{22}} \right]^{-1} \tag{A.2}$$

for a generalized array, whose value depends on the positions of the electrodes as defined in Figure 24.

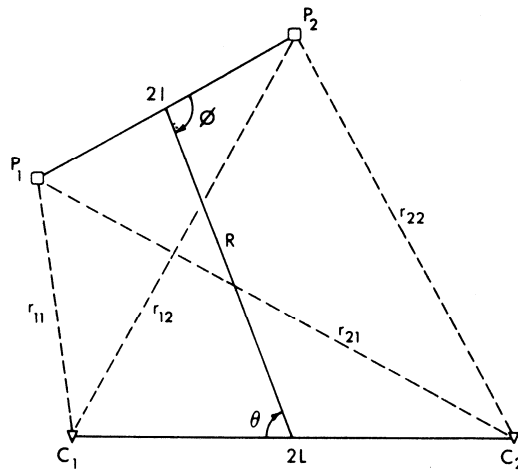


Figure 24. A generalized four-electrode array with potential electrodes P_1, P_2 and current electrodes C_1, C_2 ($0 < \theta, \varphi < \pi$)

In homogeneous ground the apparent resistivity will equal the true resistivity, but will normally be a combination of all contributing strata. Thus, the geometrically corrected quantity is called apparent resistivity (ρ_a).

Figure 25 shows examples of different collinear electrode configurations in use: Wenner (α , β and γ), Schlumberger, dipole-dipole, and pole-pole. It can be noted that the Wenner configuration is a special case where the four electrodes are equally spaced with a separation a . For the Schlumberger array the I/L -relation will vary during normal surveying, similarly the factor n will vary in a dipole-dipole survey. The different electrode configurations offers advantages and disadvantages compared to each other in terms of logistics and resolution, and the choice is usually a trade-off between these factors. Furthermore, the reciprocity principle states that the current and potential electrodes may change places without affecting the measured quantity. In some applications it may be an advantage to make use of the reciprocity principle for logistic reasons, or for estimating the measurement accuracy.

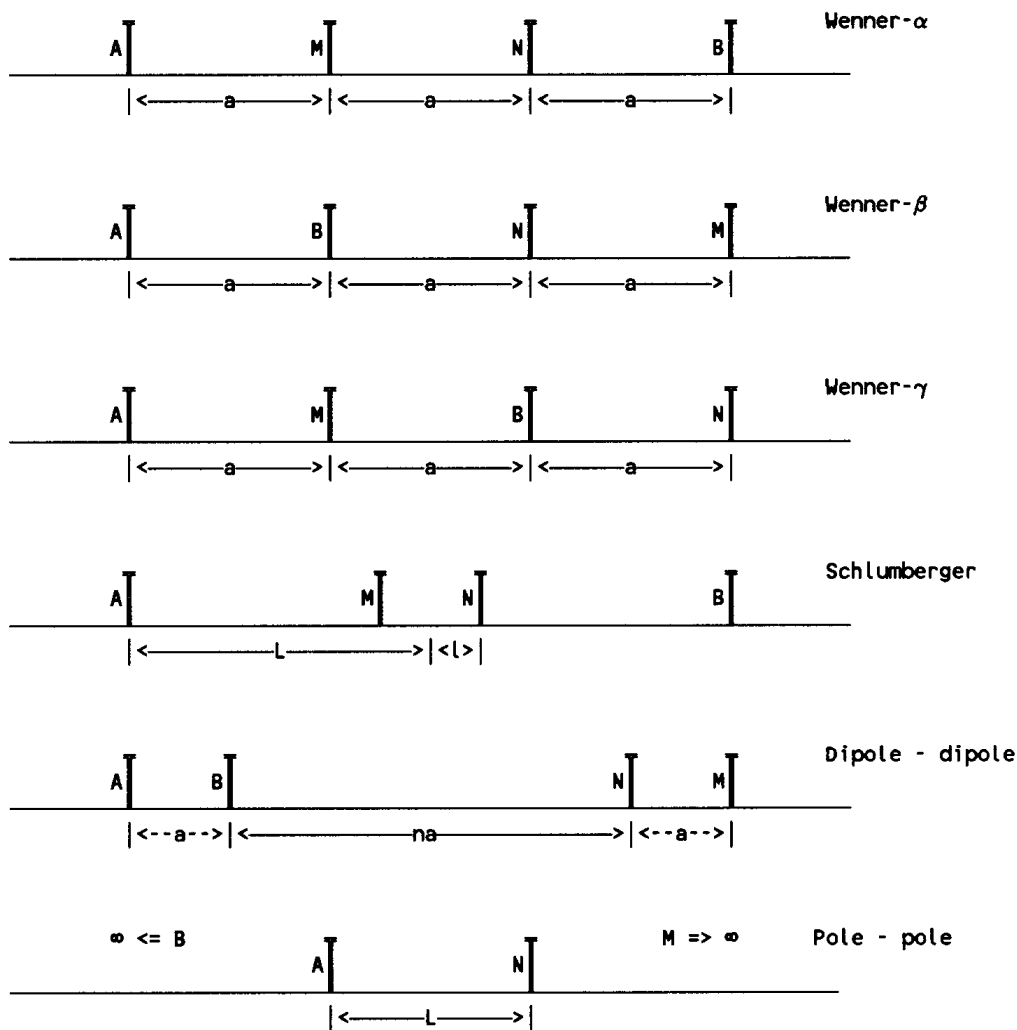


Figure 25. Examples of different electrode arrays (A and B represent current electrodes, M and N potential electrodes). Also a combination of pole-pole and dipole-dipole is possible. This configuration is denoted pole-dipole.

10.2 MULTIPLE GRADIENT ARRAY SURVEYING

The following text is mainly based on Dahlin and Zhou (2002).

10.2.1 Surveying Principles

Multi-electrode gradient surveying is carried out by injecting current with a separation $(s+2)a$ and simultaneously or sequentially picking up all the potential differences between the potential electrodes with the spacing a (Figure 1). Here s is an integer, which means the maximum number of potential readings for a current injection. Figure 2a gives a schematic representation of this array, where the sensitivity function of the measurement with the first potential electrode pair is also shown in the background. Generally, the bigger separation of current electrodes the deeper penetration of the configuration, and the smaller spacing of potential electrodes the more details of potential variation are obtained. In practical applications the selection of spacing a and separation s will be a trade-off between noise sensitivity, horizontal detail and depth penetration. Traditional gradient surveying often comprised measurements with the current electrodes at one fixed location only. In a multi-electrode gradient survey a large number of current electrode combinations are used, scanning across the electrode layout with several different spacings a and separations s , similar to multi-electrode surveying with other electrode arrays.

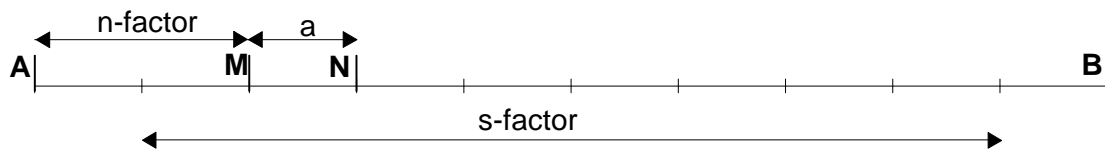


Figure 26. Sketch of gradient array layout showing the position of the electrodes for a measurement with s-factor 8 and n-factor 2.

It can be observed that the gradient array is essentially a pole-dipole array (Figure 2b) when the potential dipole is close to one of the current electrodes, at least for large s -factors. When the potential dipole is centred between the current electrodes it is identical to the Schlumberger array (Figure 2c). Thus, the gradient array may be expected to combine the characteristics of the pole-dipole and Schlumberger arrays, however without the need of a remote electrode that can be cumbersome to arrange in some environments.

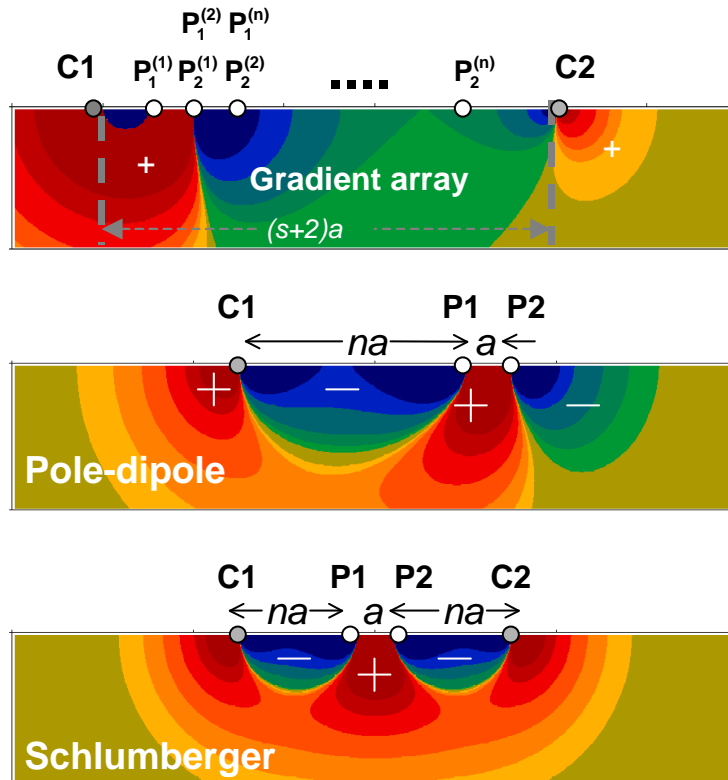


Figure 27. Schematic representations for a) gradient array, b) pole-dipole, and c) Schlumberger measurement. The background shows the sensitivity pattern of the configuration, in the gradient case for the first potential electrode pair (n -factor = 1).

10.2.2 Pseudosection Plotting

Plotting the measured apparent resistivities as pseudosection is a valuable tool for fast assessment of the data quality. Systematically varying apparent resistivity in a pseudosection usually shows that the data quality is acceptable, where a modestly experienced field crew easily picks out outliers indicating measurement technical problems. A pseudosection can also give a rough hint about the resistivity structure at the site, but must be used with great caution as the sensitivity function of different electrode arrays lead to images that are strongly distorted compared to the geometry of the imaged structures.

For the gradient protocols many data points tend to end up in the same location in the pseudosection using the formulas above, hence it is suggested that pseudosections based on several sub-sets of the data are plotted separately for data quality assessment. Furthermore, it may be useful to make separate plots for each electrode spacing a used in order to get a clear image of the data quality.

10.3 REFERENCES

- Dahlin, T. and Zhou, B. (2002) Gradient and mid-point-referred measurements for multi-channel 2D resistivity imaging, *Procs. 8th Meeting Environmental and Engineering Geophysics, Aveiro, Portugal, 8-12 September 2002*, 157-160.
- Parasnis, D.S. (1997) *Principles of Applied Geophysics*, 5:th ed, ISBN 0 412 64080 5, Chapman and Hall, London, 429p.


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- Sharma, P.V. (1997) *Environmental and Engineering Geophysics*, ISBN 0 521 57632 6, Cambridge University Press, 475p.
- Telford, W.M., Geldart, L.P. and Sheriff, R.E. (1990) *Applied Geophysics*, 2nd ed., Cambridge University Press, 770 p.
- Ward, S.H. (1989) Resistivity and Induced Polarization Methods, in *Investigations in Geophysics no. 5: Geotechnical and Environmental Geophysics, vol I*, ed. S. Ward, Society of Exploration Geophysicists, Tulsa, p 147-189.

11 APPENDIX B. TERRAMETER ERROR CODES

Whenever an error occurs in the Terrameter SAS 1000 / 4000 a code is displayed on the screen. The meaning of the codes is as follows:

<i>Error code</i>	<i>Cause</i>	<i>Remedy</i>
1	Transmitter cables or grounding have too high resistance - SAS 1000 / 4000 cannot transmit the selected current into the ground.	Check all connections - a probable cause is a broken cable or bad cable connection. Improve the electrode grounding (i.e. more electrodes connected in parallel). Decrease current or (better) select AUTO current.
2	Internal error	Contact ABEM
3	Not possible to transmit a current sufficient for the "minimum acceptable current level". <i>Only in LUND measurements.</i>	Decrease the minimum acceptable current in the appropriate menu in the LUND control program. A suitable setting is 10 mA.
4	The total resistance between C1 and C2 increased considerably during the measurement.	Check the electrode grounding. Check also if some of the cables are broken.
5	The total resistance between C1 and C2 decreased considerably (e.g. short circuit) during the measurement.	Check the electrode grounding. Check also for short circuits.
6	Overheated - the temperature in the SAS 1000 / 4000 DC/DC converter is above the acceptable level	Let the instrument cool down for a few minutes.
8	Internal A/D converter error. Registers not properly reset.	Try again. If the error persists, contact ABEM.
9	Internal A/D converter error. Register overflow.	Try again. If the error persists, contact ABEM.
12	Battery voltage dropped during a measuring cycle.	Charge / change battery. Check battery cables and connectors involved
22	General fault in transmitter circuit.	Contact ABEM
31	Negative resistance	Check electrodes and geometry, and measure again. Check if the transmitted current is too low. Geometry and nature can however, cause negative resistance.
32	Invalid current selected <i>Only in LUND measurements</i>	The selected current must be greater than the selected minimum output.

33	Internal error - invalid setup parameters	Try again. If the error persists, contact ABEM.
34	Internal error - invalid fundamental frequency	Try again. If the error persists, contact ABEM.
41	Record full	No more readings can be added to this record. Create a new record.
50	Low battery in ES 464	Change battery, or use an external power supply
51	No response from ES 464 (LUND Imaging System)	Check cables. Check ES 464 battery. Make sure the "Serial" connector on the SAS 1000 / 4000 is not connected to any other device.
52	No more items in LUND protocol file	Check the protocol file
54	The specified protocol could not be found in the database PROTOCOL.BIN	Check the protocol files. Recompile the files and download again.
55	One or more addressed electrode positions are outside the physical layout	Check the electrode positions in the protocol file.
56	Quit the protocol	
57	Bad connection or no connection during electrode test. One or more electrodes.	Check and improve the electrode grounding.
58	Bad connection or no connection at all at remote current electrode	Check and improve the electrode grounding.
59	No connection at any electrode	Check cables
60	Skip the rest of this protocol	
61	Bad version of LUND protocol	The protocol read from disk is not compatible with the program version. Compile the protocol files with a version of MPFC of same generation as the main SAS 1000 / 4000 program.
62	LUND connection error	Contact ABEM
63	No (or too few) ES464 units connected	Check communication cables and the power to each ES464 unit.
70	Multimac logical communication error	

71	Multimac general error	
72	More than one electrode connected	Check the electrode switcher(s)
74	Connection error Multimac	
75	No electrodes at all connected	
76	Quit Multimac measurement	
77	The addressed Multimac electrode does not exist	
79	No user defined protocol for Multimac with this name could be found in the database	
80	The geometry file specified in the protocol file could not be found in the database.	
81	Not all electrodes could be connected	
82	Not all electrodes could be disconnected	
83	Error when trying to get Multimac status	
84	Insignificant error	Ignore this error message
99	User break. The user has pressed the quit knob  during a measurement.	This is not a system error - repeat the measurement if needed.
100	The disk is full and no more data can be stored	Transfer data to a computer and clean the SAS 1000 / 4000 memory.

12 APPENDIX C. MPFC ERROR CODES

There are a number of error codes associated with the MPFC.EXE program, as listed below. Errors are fatal and cause no database file to be created while warnings are non-fatal and a database file will be created.

For example, if only an ORG-file has been created and no UP- and DWN-files a warning will be issued. As it is fully legal to define only an ORG-file the compiler accepts this but warns the user that he/she might have missed to supply the UP- and DWN-files.

The possible error codes in MPFC program.

Code	Message
1000	Empty line in definition file for Electrode Layout Codes.
1031	Could not find a '.DWN' file corresponding to the current '.ORG' file.
1032	Could not find a '.UP' file corresponding to the current '.ORG' file.
1033	Could not find a '.MM' file
1501	An electrode number refers to a relay address equal to zero. This is only a warning.
2000	Missing Electrode Layout Code for keyword.
2001	Duplicate key found.
2003	Could not find a layout code corresponding to the keyword.
2101	Error in scanning geometry files '.XYZ'
3000	Could not open the protocol file (.ORG, .DWN or .UP)
3001	Could not find the '.ADR' file stated in the source file.
3002	Could not open the '.ADR' file stated in the source file.
3011	Syntax error in electrode mapping. Three numerical values are required (the last is an expression X-Y).
3021	Electrode position is out of limits.
3022	Relay address is out of limits.
3023	Cable number is out of limits.
3024	Takeout number is out of limits.
3025	The whole or a part of this address has already been defined. All addresses must be unique.
3026	This electrode position has already been defined. All positions must be unique.
3027	An electrode number did not map to a valid relay address.
3101	Invalid number of parameters.

3102	One of n_{x-move} or n_{y-move} must be zero. The layout can only be moved in either the X- or Y-direction.
3201	Could not open a .MM file
3202	Could not find the referred geometry file .XYZ
3203	Too few arguments to the command on the Multimap protocol file
3204	Too many arguments to the command on the Multimap protocol file
3205	At least one value in the parsed command was out of limits
4001	Syntax error, invalid command.
4011	Syntax error in command. Four numerical values are required.
4012	One or more of the values have a duplicate in this command.
4013	The electrode numbers were defined in an incorrect order in the context of the selected electrode configuration.
4014	In four-electrode configurations there should never be a "zero" electrode.
4015	Unexpected electrode(s).
4051	Too many entries in the protocol file.
4101	Could not interpret the contents of the '.ADR' file. Further processing not possible.
9011	Could not find/open the Electrode Layout Code File.
9012	The Electrode Layout Code File did not contain any valid code definitions.

13 APPENDIX D. ES464 / ES10-64 ADDRESS, TAKE-OUT AND PIN CONNECTOR RELATION

The following table describes the connection between the address, the cable take out and the pin in the connectors when using all three connectors (left) or only the two connectors (right). The four-cable configuration assumes a set of standard Lund Imaging System electrode cables with 21 take-outs each. The four-cable configuration applies to ES10-64 as well.

Three-cable configuration					Four-cable configuration				
ADR	Cable 1	Cable 2	Cable 3	PIN	Cable 1	Cable 2	Cable 3	Cable 4	PIN
1	1			A		1			A
2	2			B		2			B
3	3			C		3			C
4	4			D		4			D
5	5			E		5			E
6	6			F		6			F
7	7			G		7			G
8	8			H		8			H
9	9			J		9			J
10	10			K		10			K
11	11			L		11			L
12	12			M		12			M
13	13			N		13			N
14	14			P		14			P
15	15			R		15			R
16	16			S		16			S
17	17			T		17			T
18	18			U		18			U
19	19			V		19			V
20	20			W		20			W
21	21			X		21			X
22			11	M	1				Y
23			12	N	3				Z
24			13	P	5				a
25			14	R	7				b
26			15	S	9				c
27			16	T	11				d
28			17	U	13				e
29			18	V	15				f
30			19	W	17				g
31			20	X	19				h
32			21	Y	21				j
33		1		A			1		A
34		2		B			2		B
35		3		C			3		C
36		4		D			4		D
37		5		E			5		E
38		6		F			6		F
39		7		G			7		G

ABEM Terrameter SAS 1000 / 4000

40	8	H	8	H
41	9	J	9	J
42	10	K	10	K
43	11	L	11	L
44	12	M	12	M
45	13	N	13	N
46	14	P	14	P
47	15	R	15	R
48	16	S	16	S
49	17	T	17	T
50	18	U	18	U
51	19	V	19	V
52	20	W	20	W
53	21	X	21	X
54		1 A	1	Y
55		2 B	3	Z
56		3 C	5	a
57		4 D	7	b
58		5 E	9	c
59		6 F	11	d
60		7 G	13	e
61		8 H	15	f
62		9 J	17	g
63		10 K	19	h
64			21	j

14 APPENDIX E. ADDRESS AND PROTOCOL FILES

14.1 EXAMPLE ADDRESS FILES

Example Address Files for CVES

The following file (LONG32.ADR) is used when four electrode cables are arranged on a line and linked together to the Electrode Selector, used for roll-along in the direction of the cable layout. Every second electrode take-out is active.

```

4 21          {number of electrode cables, number of take-outs per electrode cable}
2 10          {electrode spacing multiplication factor for long layout, total no of lengths of one cable}
41           {total number of active electrode take-outs}
1   22   1-1  {Col 1: electrode identification number, corresponding to numbers in protocol file}
2   23   1-3  {Col 2: internal relay address according to the above table 8-1}
3   24   1-5  {Col 3: physical position (cable no. - take-out no.) }
4   25   1-7
5   26   1-9
6   27   1-11
7   28   1-13
8   29   1-15
9   30   1-17
10  31   1-19
11  1     2-1
12  3     2-3
13  5     2-5
14  7     2-7
15  9     2-9
16  11    2-11
17  13    2-13
18  15    2-15
19  17    2-17
20  19    2-19
21  21    2-21
22  35    3-3
23  37    3-5
24  39    3-7
25  41    3-9
26  43    3-11
27  45    3-13
28  47    3-15
29  49    3-17
30  51    3-19
31  53    3-21
32  55    4-3
33  56    4-5
34  57    4-7
35  58    4-9
36  59    4-11
37  60    4-13
38  61    4-15
39  62    4-17
40  63    4-19
41  64    4-21

```

Next example shows an address file (SHORT32.ADR) used when two cables are arranged on a line and connected to the Electrode Selector, used for roll-along in the direction of the cable layout. Every electrode take-out is active, apart from one of the overlapping ones:

```

4 21          {number of electrode cables, number of take-outs per electrode cable}
1 20          {electrode spacing multiplication factor for long layout, total no of lengths of one cable}
41           {total number of active electrode take-outs}
1   1     2-1
2   2     2-2
3   3     2-3
4   4     2-4
5   5     2-5
6   6     2-6
7   7     2-7
8   8     2-8
9   9     2-9
10  10    2-10

```

11	11	2-11
12	12	2-12
13	13	2-13
14	14	2-14
15	15	2-15
16	16	2-16
17	17	2-17
18	18	2-18
19	19	2-19
20	20	2-20
21	21	2-21
22	34	3-2
23	35	3-3
24	36	3-4
25	37	3-5
26	38	3-6
27	39	3-7
28	40	3-8
29	41	3-9
30	42	3-10
31	43	3-11
32	44	3-12
33	45	3-13
34	46	3-14
35	47	3-15
36	48	3-16
37	49	3-17
38	50	3-18
39	51	3-19
40	52	3-20
41	53	3-21

Example Address Files for Areal/3D Cover

For roll-along perpendicular to the direction of cable extension a little additional information is needed, specifying that cables are moved for roll-along in the y-direction instead and the number of take-outs in x-direction. The following file (SIDEBY32.ADR) is intended for measuring with three electrode cables parallel to each other, and connected directly to the Electrode Selector:

```

3 21
1 0 1           {electrode spacing multiplication factor for short layout, no. of lengths for x-move, no. of lengths for y-move}
63 21
1 1 1-1
2 2 1-2
3 3 1-3
4 4 1-4
5 5 1-5
6 6 1-6
7 7 1-7
8 8 1-8
9 9 1-9
10 10 1-10
11 11 1-11
12 12 1-12
13 13 1-13
14 14 1-14
15 15 1-15
16 16 1-16
17 17 1-17
18 18 1-18
19 19 1-19
20 20 1-20
21 21 1-21
22 33 2-1
23 34 2-2
24 35 2-3
25 36 2-4
26 37 2-5
27 38 2-6
28 39 2-7
29 40 2-8
30 41 2-9
31 42 2-10
32 43 2-11
33 44 2-12

```

```

34 45 2-13
35 46 2-14
36 47 2-15
37 48 2-16
38 49 2-17
39 50 2-18
40 51 2-19
41 52 2-20
42 53 2-21
43 22 3-1
44 23 3-2
45 24 3-3
46 25 3-4
47 26 3-5
48 27 3-6
49 28 3-7
50 29 3-8
51 30 3-9
52 31 3-10
53 32 3-11
54 54 3-12
55 55 3-13
56 56 3-14
57 57 3-15
58 58 3-16
59 59 3-17
60 60 3-18
61 61 3-19
62 62 3-20
63 63 3-21

```

14.2 EXAMPLE PROTOCOL FILES

Example: Wenner Array Protocol File

The following example is extracted from a protocol file used for Wenner CVES (single channel):

```

1          Wenner-a
LONG32    Long array, measuring sequence large to small spacings.
1 37 13 25
2 38 14 26
3 39 15 27
4 40 16 28
5 41 17 29
1 31 11 21
2 32 12 22
...
18 21 19 20
21 24 22 23
24 27 25 26
27 30 28 29
30 33 31 32
33 36 34 35
36 39 37 38

```

Example: Dipole-dipole Array Protocol File

The following example is extracted from a protocol file used for 4-channel dipole-dipole array CVES (note order of current electrodes):

```

11          10          4          DIPOLE-DIPOLE
SHORT      Dipole-dipole array for 4 channel measuring w. SAS4000 + ES10-64
2 1 3 4 5 6 7 8 9 10
2 1 4 5 6 7 8 9 10 11
3 2 4 5 6 7 8 9 10 11
3 2 5 6 7 8 9 10 11 12
4 3 5 6 7 8 9 10 11 12
4 3 6 7 8 9 10 11 12 13
5 4 6 7 8 9 10 11 12 13
5 4 7 8 9 10 11 12 13 14
6 5 7 8 9 10 11 12 13 14
6 5 8 9 10 11 12 13 14 15

```

Example: Gradient Array Protocol File

The following example is extracted from a protocol file used for 4-channel multiple gradient array CVES:

```

11      10      4      GRADIENT
LONG    Gradient array for 4 channel measuring w. SAS4000 + ES10-64
1 31 4 7 10 13 16 19 22 25
1 31 7 10 13 16 19 22 25 28
2 32 5 8 11 14 17 20 23 26
2 32 8 11 14 17 20 23 26 29
3 33 6 9 12 15 18 21 24 27
3 33 9 12 15 18 21 24 27 30
4 34 7 10 13 16 19 22 25 28
4 34 10 13 16 19 22 25 28 31
5 35 8 11 14 17 20 23 26 29
5 35 11 14 17 20 23 26 29 32
6 36 9 12 15 18 21 24 27 30
6 36 12 15 18 21 24 27 30 33
7 37 10 13 16 19 22 25 28 31

```

Example: Pole-pole Array Protocol File using one channel

A protocol file for single channel pole-pole could look like this:

```

4      Pole-pole
LONG32 Pole-pole, long array
0 1 0 31
0 1 0 25
0 1 0 21
0 1 0 17
0 1 0 13
0 1 0 11
0 1 0 9
0 1 0 7
0 1 0 6
0 1 0 5
0 1 0 4

```

Example: Pole-pole Array Protocol File using three channels (POL3SS)

A protocol file for three channel pole-pole (using ES 464 with the special adapter 33 0020 14) could look like this:

```

4      Pole Pole
SHORT32
1      13      17      21
1      5       7       9
1      2       3       4
2      14      18      22
2      6       8       10
2      3       4       5
3      15      19      23
...
30     31      32      33
31     35      37      39
31     32      33      34
32     36      38      40
32     33      34      35
33     37      39      41
33     34      35      36
34     37      38      40
34     35      36      0
35     38      39      41
35     36      37      0
36     38      39      40
36     37      0       0
37     39      40      41
37     38      0       0
38     39      40      41
39     40      41      0
40     41      0       0

```


14.3 EXAMPLE LOCATION / GEOMETRY FILE

The electrode coordinates for a borehole measurement are entered via a location or geometry file (textfile with LOC or XYZ file extension). Here is an example:

```

3
Surface cable
1   -2   0   0
2    0   0   0
3    2   0   0
4    4   0   0
5    6   0   0
6    8   0   0
7   10   0   0
8   12   0   0
9   14   0   0
10  16   0   0
11  18   0   0
12  20   0   0
13  22   0   0
14  24   0   0
15  26   0   0
16  28   0   0
17  30   0   0
18  32   0   0
19  34   0   0
20  36   0   0
21  38   0   0
Borehole cable #1
1    0    0    2
2    0    0    4
3    0    0    6
4    0    0    8
5    0    0   10
6    0    0   12
7    0    0   14
8    0    0   16
9    0    0   18
10   0    0   20
11   0    0   22
12   0    0   24
13   0    0   26
14   0    0   28
15   0    0   30
16   0    0   32
17   0    0   34
18   0    0   36
19   0    0   38
20   0    0   40
21   0    0   42
Borehole cable #2
1   36    0    2
2   36    0    4
3   36    0    6
4   36    0    8
5   36    0   10
6   36    0   12
7   36    0   14
8   36    0   16
9   36    0   18
10  36    0   20
11  36    0   22
12  36    0   24

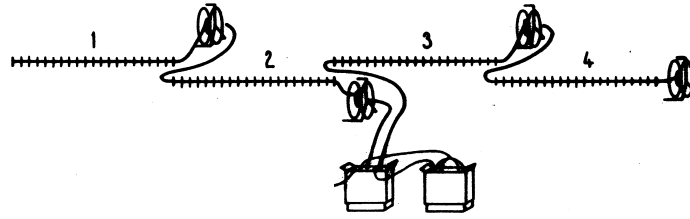
```

ABEM Terrameter SAS 1000 / 4000

13	36	0	26
14	36	0	28
15	36	0	30
16	36	0	32
17	36	0	34
18	36	0	36
19	36	0	38
20	36	0	40
21	36	0	42

The following pages describe example protocol files supplied with the Lund Imaging System.

14.4 WENNER_L + WENNER_S: 1-CHANNEL WENNER CVES WITH 4 ELECTRODE CABLES



This combination of protocol files is intended for Wenner- α CVES roll-along measurements, and has been found very useful for a variety of applications. Note that it is important to select the protocol files in the correct order, starting with the long layout (WENNER_L) before selecting the protocol for short layout (WENNER_S). It gives a dense near-surface cover, and a slightly sparser measurement pattern at long electrode spacings. The WENNER_L protocol supplied here has a higher data density than in previous releases, being identical to the previously supplied WENNERXL.

WENNER_S is designed only to supplement WENNER_L for the shortest electrode spacings, and is generally not suitable for use alone if only the two center cables are used. If measuring with two cables only, either use WENNER_L and exclude all electrode positions on the outer electrode cables, or use a protocol dedicated for using two electrode cables only (see below).

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
WENNER_L	Wenner- α	LONG	258	113
WENNER_S	Wenner- α	SHORT	87	50
Sum			345	163

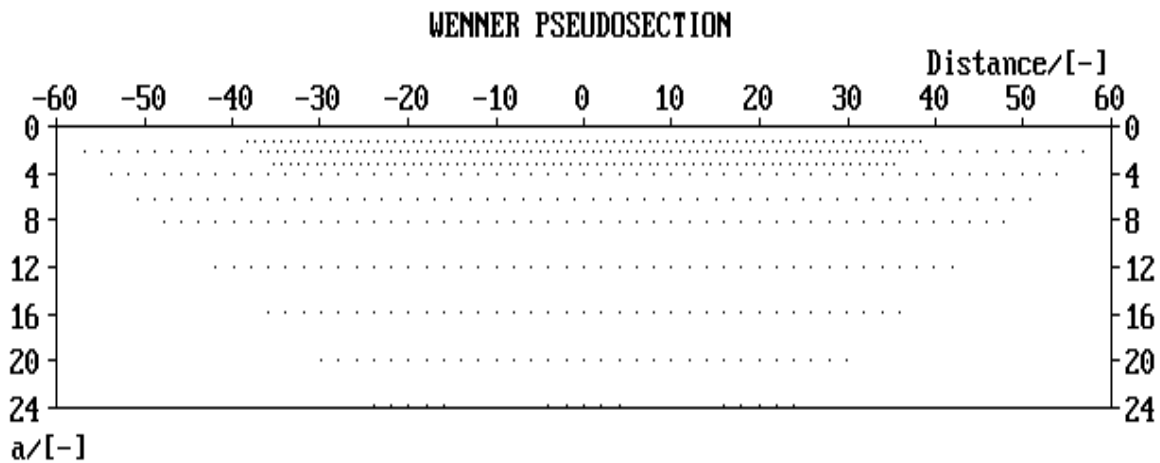
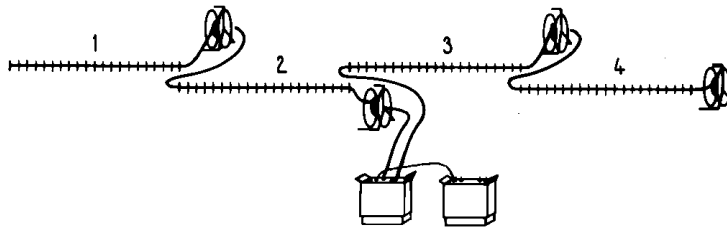


Figure 28: Data cover of standard Wenner CVES using WENNER_L and WENNER_S for roll-along with three stations (take-out spacing 1metre).

14.7 POLDIP4L + POLDIP4S: 4-CHANNEL POLE-DIPOLE ARRAY CVES WITH 4 ELECTRODE CABLES



+ REMOTE ELECTRODE

This combination of protocol files is intended for dipole-dipole array CVES roll-along measurements, and has been found very useful for a variety of applications. It offers a resolution superior to the commonly used Wenner array, and thanks to 4-channel measuring the increased data density does not become costly in terms of increased time required in the field. It has a larger depth penetration, but requires a remote electrode that may be problematic in practice. Due to the character of the array some duplicate data points can occur when doing roll-along. Note that it is important to select the protocol files in the correct order, starting with the long layout (POLDIP4L) before selecting the protocol for short layout (POLDIP4S). It gives a dense near-surface cover, and a slightly sparser measurement pattern at long electrode spacings. POLDIP4S is designed to supplement POLDIP4L for the shortest electrode spacings only.

Array type	Protocol name	Address file	No of data ORG	No of data UP	No of data DWN	Total data for one layout ¹⁵
Pole-dipole	POLDIP4L	LONG	584	292	-	1651
	POLDIP4S	SHORT	288	284	-	

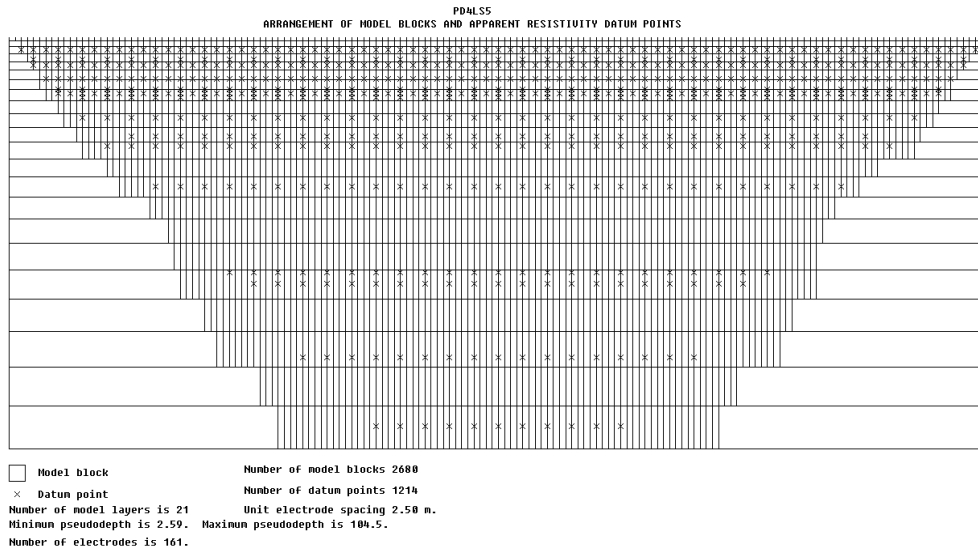
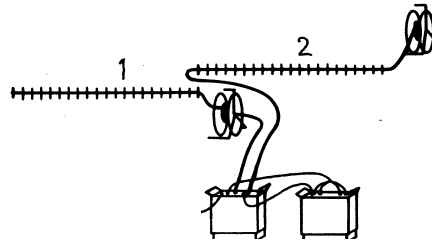


Figure 31. Data cover of POLDIP4L and POLDIP4S for roll-along with three full stations (minimum electrode spacing 5 metres).

¹⁵ Total number of data points for a four-cable layout using the procedure described in this manual.

14.10 WEN32SX: 1-CHANNEL WENNER CVES WITH 2 ELECTRODE CABLES



This protocol file is intended for Wenner- α CVES roll-along measurements with 2 cables only, i.e. it is not reduced for long array overlap.

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
WEN32SX	Wenner- α	SHORT	190	138

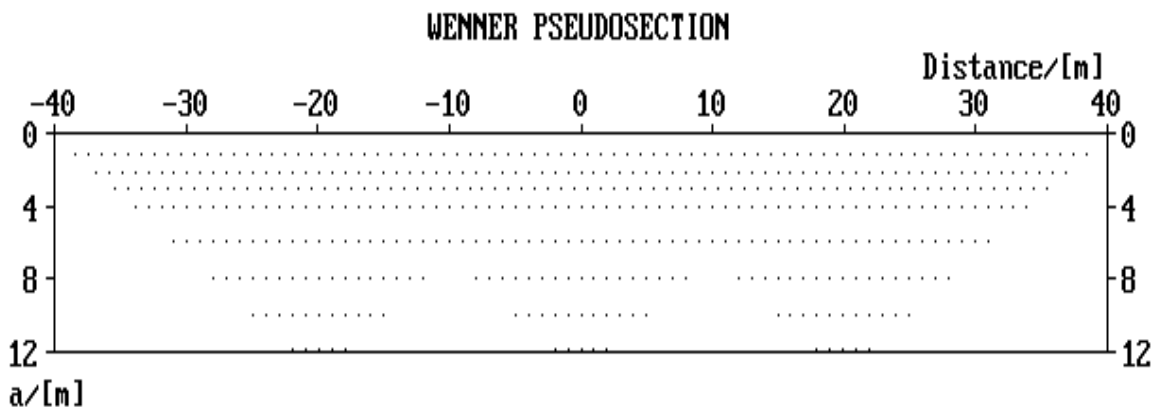
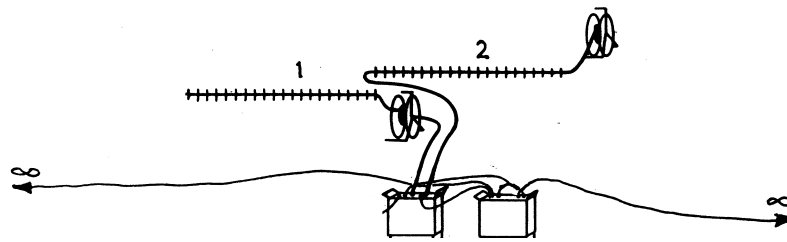


Figure 34: Data cover of Wenner CVES using WEN32SX for roll-along with three stations (take-out spacing 1metre).

14.11 POL3SS: 3-CHANNEL POLE-POLE CVES WITH 2 ELECTRODE CABLES



Please observe that C2 and P2 are the remote electrodes.

This measurement protocol is designed for pole-pole CVES using only two standard cable sections, addressing each electrode take-out. The number of measurement combinations included is only a fraction of the total possible number of independent combinations using the pole-pole array (820 combinations), but designed to give an even roll-along cover and reducing the measurement time.

The POL3SS protocol is designed for using three measuring channels using SAS4000 and ES464. In order to measure with three channels you need the optional "Pole-Pole" interconnection cable between the SAS4000 and the ES464, order no. 33 0020 14.

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
POL3SS	Pole-pole	SHORT	297(106)	180(74)

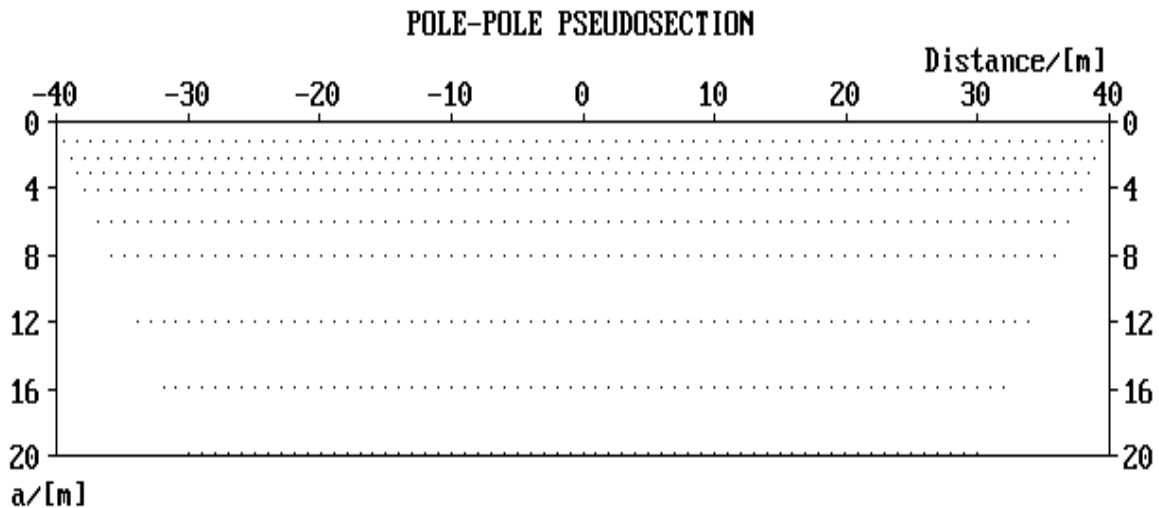
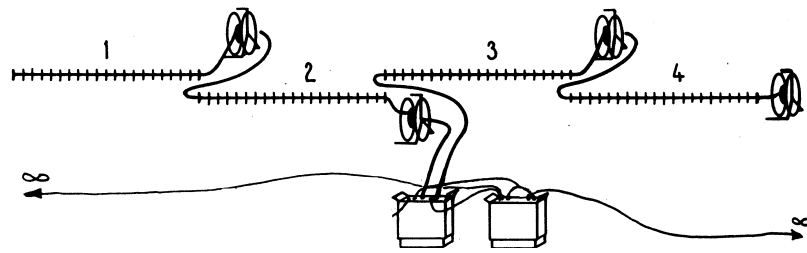


Figure 35. Data cover of 3 station roll-along for pole-pole CVES using POL3SS (take-out spacing 1metre).

14.12 POL3L: 3-CHANNEL POLE-POLE CVES WITH 4 ELECTRODE CABLES



Please observe that C2 and P2 are the remote electrodes.

This measurement protocol is designed for pole-pole CVES using four standard cable sections linked together, addressing every fourth electrode take-out. The number of measurement combinations included is less than half of the total possible number of independent combinations using the pole-pole array (820 combinations), but designed to give an even roll-along cover and reducing the measurement time.

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
POL2L	Pole-pole	LONG32	392	130
POL3L	Pole-Pole	LONG32	146	58

The POL3L protocol is identical to the POL2L, with the exception that it is designed for using three measuring channels on the SAS 4000. Please note, that using this protocol the measuring time is reduced by a factor of 2.2 to 2.7. In order to measure with three channels you need the optional "Pole-Pole" interconnection cable between the SAS 4000 and the ES 464, order no. 33 0020 14.

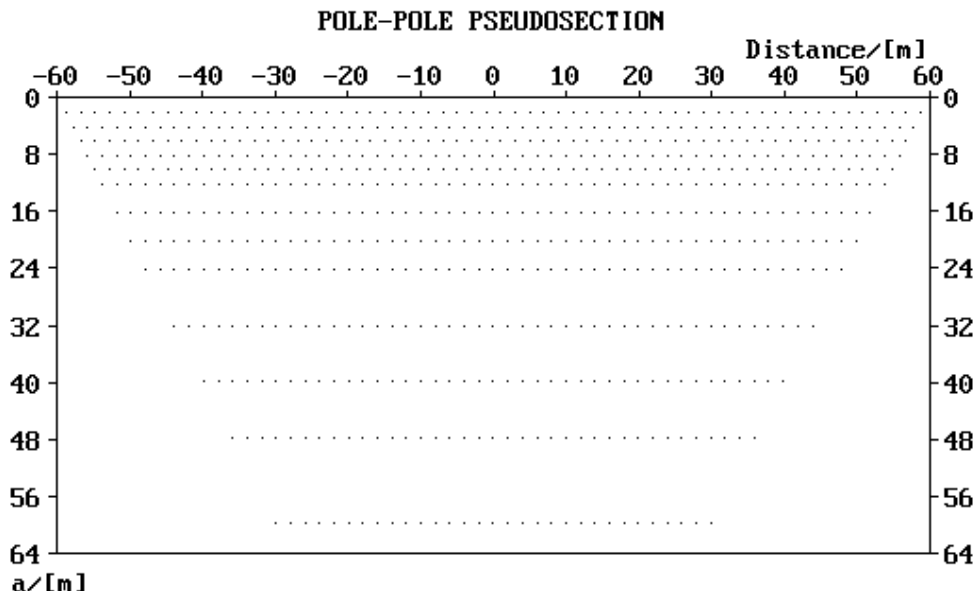
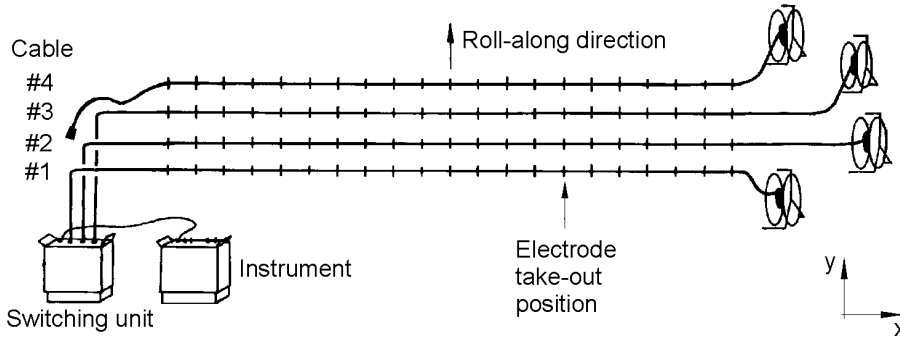


Figure 36. Data cover of 3 station roll-along for pole-pole CVES using POL3L (take-out spacing 1metre).

14.13 SQUARE2A, SQUARE2B AND SQUARE2C: SQUARE ARRAY AREA COVER WITH TWO ELECTRODE SPACINGS



These protocol files are intended for area cover with roll-along perpendicular to the layout direction of the cables. The roll-along direction can be in either direction depending on if a right handed or left handed coordinate system is preferred (often the opposite direction to as what is illustrated above is preferable). Two electrode spacings are measured: 1x and 2x the take-out spacing. Observe that there is no support in RES3DINV for this electrode configuration, and that it is not suitable for 3D inversion due to limited depth cover!

Note that it is not possible to calculate an apparent resistivity for the square- γ array: in homogeneous ground no potential is measured!

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
SQUARE2A	Square- α	SQUARE32	59	39
SQUARE2B	Square- β	SQUARE32	59	39
SQUARE2C	Square- γ	SQUARE32	59	39
Sum			177	117

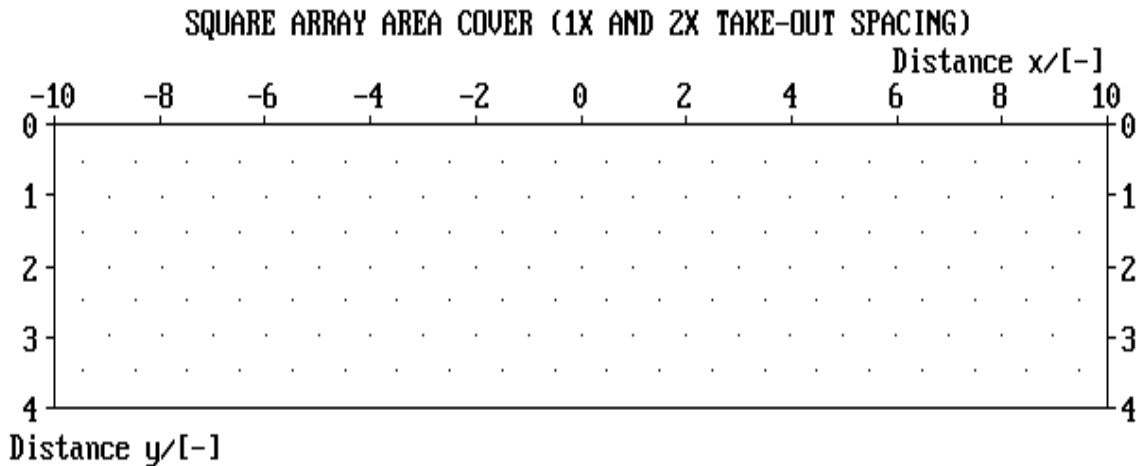


Figure 37. Data cover for roll-along with three stations of square array area measurements using SQUARE2A, SQUARE2B or SQUARE2C.

14.14 POL8X8: POLE-POLE IN 8X8 SQUARE GRID

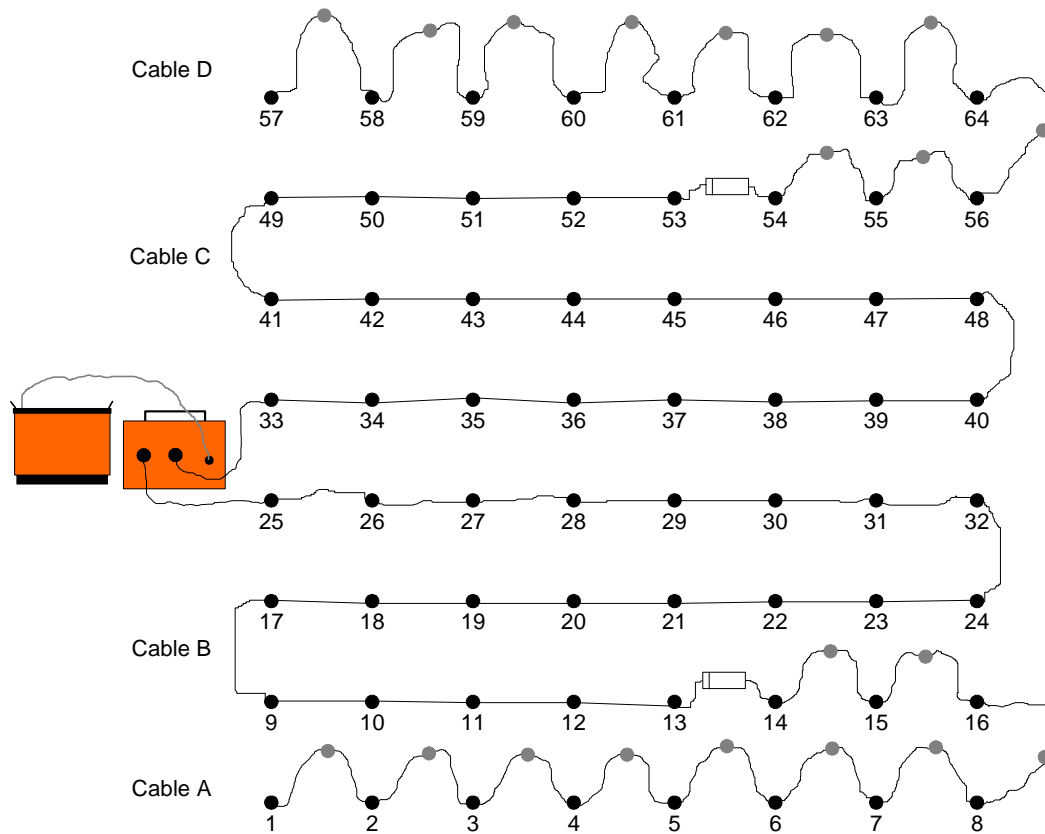


Figure. Sketch of 8 x 8 electrode layout using 4 standard Lund cables with 21 take-outs each. The cables are connected so that take-out 1 is closest to the instrument. Note that every second electrode take-out on the outer cables is skipped (grey take-outs in the sketch), and there is no overlap of electrodes between the inner and outer cables.

This protocol file is designed for 3D surveying using the pole-pole array. Observe that every electrode take-out is used on the two cables closest to the electrode selector, and every second take-out used on the outer two cables. Furthermore, there shall be no overlap at the cable joints.

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
POL8X8	Pole-pole	8X8	728	-

Note:

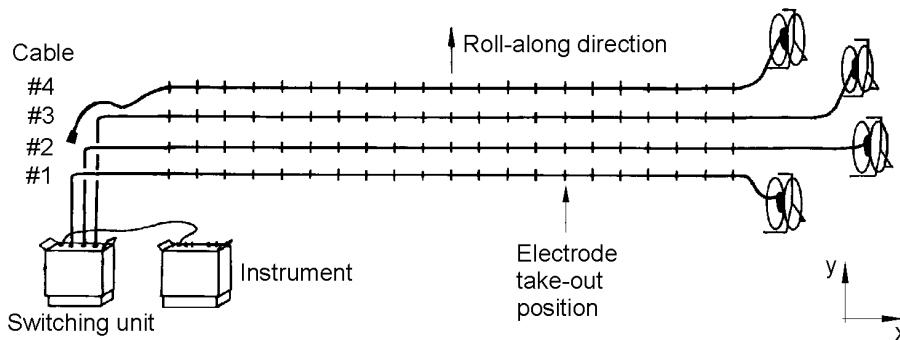
The logical arrangement of the address file in this case is such that it appears as 8 parallel cables to the data acquisition software, i.e. electrode 1-8 in the sketch appears as cable 1, electrode 9-16 appears as cable 2, etc.. Observe that in this case it does not match the labelling on the cables at all! The address file describes the physical configuration of the cable, and how the electrode take-outs are wired to the internal addresses of the relay switch, and can as in this case be used to arrange cables in a different way than originally intended. Note also that the protocol file in turn only refers to the electrode numbers.

For 3D surveys, however, an 8x8 layout is very small. It is generally more convenient to carry out a 3D survey as a number of parallel, and possibly also perpendicular 2D lines that, may later be assembled to a 3D data set (see “3D Resistivity Surveying by Means of a Number of 2D Layouts” on page 43).

Table. Distribution of electrode position numbers according to sketch in relation to take-out numbers on the electrode cables.

A-1	14	B-1	25	C-1	33	D-1	54
A-2	-	B-2	26	C-2	34	D-2	-
A-3	15	B-3	27	C-3	35	D-3	55
A-4	-	B-4	28	C-4	36	D-4	-
A-5	16	B-5	29	C-5	37	D-5	56
A-6	-	B-6	30	C-6	38	D-6	-
A-7	8	B-7	31	C-7	39	D-7	64
A-8	-	B-8	32	C-8	40	D-8	-
A-9	7	B-9	24	C-9	48	D-9	63
A-10	-	B-10	23	C-10	47	D-10	-
A-11	6	B-11	22	C-11	46	D-11	62
A-12	-	B-12	21	C-12	45	D-12	-
A-13	5	B-13	20	C-13	44	D-13	61
A-14	-	B-14	19	C-14	43	D-14	-
A-15	4	B-15	18	C-15	42	D-15	60
A-16	-	B-16	17	C-16	41	D-16	-
A-17	3	B-17	9	C-17	49	D-17	59
A-18	-	B-18	10	C-18	50	D-18	-
A-19	2	B-19	11	C-19	51	D-19	58
A-20	-	B-20	12	C-20	52	D-20	-
A-21	1	B-21	13	C-21	53	D-21	57

14.15 POL21X7A-F: 3 CHANNEL POLE-POLE 3D ROLL-ALONG SURVEYING



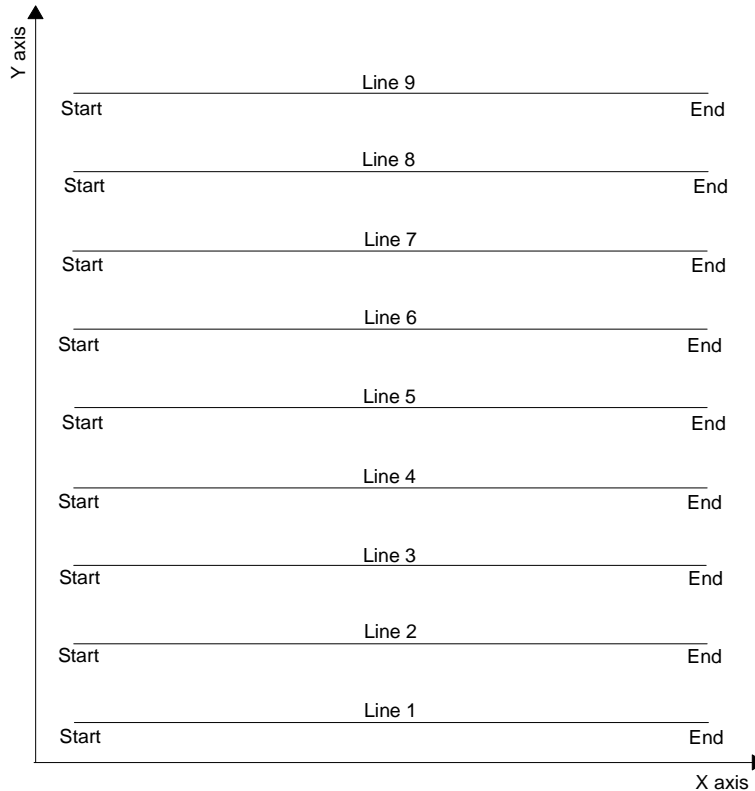
These protocol files are intended for area cover with roll-along perpendicular to the layout direction of the cables, using the special adapter cable for 3 channel measurement using Terrameter SAS4000 and one unit ES464. The roll-along direction can be in either direction depending on if a right handed or left handed coordinate system is preferred (often the opposite direction to as what is illustrated above is preferable). Two remote electrodes are required at a distance of preferably 10 times the maximum electrode separation or more. These protocol files have a data cover identical to the survey presented by Dahlin et al (2002)¹⁸.

These protocol files are provided as an example, but similar protocols for the combination SAS4000 and ES10-64 are not recommended. According to numerical modelling studies e.g. the pole-dipole array is preferable, as it would give better resolution, is easier in terms of field logistics with only one remote electrode, and furthermore is less sensitive to noise. Furthermore, a 3-cable adapter would be needed to connect three cables to the ES10-64.

See also “3D Resistivity Surveying by Means of a Number of 2D Layouts” on page 43.

¹⁸ Dahlin, T., Bernstone, C., and Loke M. H. (2002). A 3D resistivity investigation of a contaminated site at Lernacken in Sweden, *Geophysics*, 67(6), 1692-1700.

14.16 POLDIP_A AND POLDIP_O: 4 CHANNEL POLE-DIPOLE 2D TO 3D SURVEYING



These protocol files are intended for area cover via a number of 2D sections that are combined into a 3D data set (see “3D Resistivity Surveying by Means of a Number of 2D Layouts” on page 43), using Terrameter SAS4000 and ES10-64. Measurements can be taken with cable layout in one direction only, as indicated in the sketch above, or by adding perpendicular layout measurements as well. One remote electrode is required at a distance of preferably at least 10 times the maximum electrode separation. It is recommended not to exceed line separations of more than twice the electrode spacing.

The POLDIP_O only contains the measurement combinations with odd n-factors, forward and reverse, whereas the POLDIP_A protocol contains both odd and even measurement combinations. The former is thus much faster to measure.

<u>Protocol</u>	<u>Array Type</u>	<u>Address File</u>	<u>Size .ORG</u>	<u>Size .UP/.DWN</u>
POLDIP_O	Pole-dipole	ONECABLE	206	-
POLDIP_A	Pole-dipole	ONECABLE	394	-

These protocol files are provided as an example, and similar protocols for other electrode arrays can be used as well. One advantage of the pole-dipole array is good depth penetration and good data cover near the ends of the layout, which is important when operating in confined spaces. Dipole-dipole and/or multiple gradient array protocols are recommend if it is practical to avoid using a remote electrode.

15 APPENDIX F. S4KCONV

15.1 DESCRIPTION

This conversion utility reads each file defined in the file specification and converts it according to selected type and options. Please note that some options are valid only for a limited number of types of conversion and/or types of data.

The program does not check for already existing output files. Thus, it will overwrite previous conversions if there are files with same name as the output files of the current conversion.

All conversions are performed in the current directory.

S4KCONV.EXE is a MS-DOS program to convert TERRAMETER SAS 1000 / 4000 S4K-datafiles to formats readable by interpretation and presentation programs. Normally the Terrameter Utilities program performs the conversion. In some cases, however, it is necessary to perform the conversion manually by using the DOS program according to the instructions below.

15.2 SYNTAX

```
s4kconv -type [-options] [wildcard/@filename]
```

-F:type

- a Convert data to ABEM Multi Purpose Format (ASCII-text). Output file extension: *.AMP*
- e Convert data to ERIGRAPH format. Output file extension: *.DAT*
- r Convert data to RES2DINV format. Output file extension: *.DAT*
- p Convert data to Interpex RESIX IP format. Output file extension *.RPD*
- x Convert data to Interpex RESIX Plus format. Output file extension *.DAT*
- 3 Convert data to RES3DINV format. Output file extension *.DAT*

-options

- c:[1,2,3,4] Do not convert the specified channels.
- G:filename Include topography data, where *filename* is the name of the file containing the topography data
- k:n0[,n1] Skip the first *n0* data points. If *n1* is not specified the conversion continues until end of file is encountered.
- m:r,h,a,b Underwater survey. r=water resistivity in Ωm , h=distance between water surface and local datum, a=left limit of water boundary (x-coordinate), b=right limit of water boundary (x-coordinate).
- n Discard negative resistivity values.
- p Discard positive resistivity values.
- R Forced conversion to apparent resistivity instead of chargeability. Valid for IP records only.

- i:*nn* Use chargeability for interval *nn* only. Valid for IP records only.
- s:[*mm,nn*] Sum chargeabilities of intervals *mm* to *nn*. If only one value is given, chargeabilities will be summed from interval 1 to *nn*.
- t:*n* Error threshold (%). Rejects data with measurement error greater than the specified threshold.
- u Unconditional conversion. Data are always converted regardless of any other options.
- w Overwrite existing output files.
- x Convert to resistance (AMP conversion only).
- z[0/1/2/3] Output electrode locations in XYZ format, i.e. C1, C2, P1 and P2 with all x,y,z coordinates specified. 0=output only station number, 1=output only x-coordinate, 2=output x and y coordinates, 3=output x,y,z coordinates (3 is default).
- ! Output sample number instead of running index
- g:x,y,z Specify new grid spacing
- b Append protocol file name as comment to each line
- L Output all measurements from SASLOG file
- N Negate all readings (multiply by -1)
- V:filename Log file in which the program messages are output

wildcard

Any valid MS-DOS wildcard specification. Default is *.S4K.

@filename

Converts the files listed in the file given by *filename*.

15.3 EXAMPLES

1. Convert all S4K-files to formatted ASCII text format:
s4kconv -F:a
2. Convert all IP records acquired using the Lund Imaging System to RES2DINV format, summing the chargeabilities of intervals 2 to 5 and discarding points with negative apparent resistivity:
s4kconv -F:r -s:2,5 li.s4k*
3. Convert all records in the above example but extract apparent resistivity instead of chargeabilities, discarding negative apparent resistivities:
s4kconv -F:r -R -n li.s4k*
4. Convert all resistivity records to ERIGRAPH format, discarding negative apparent resistivities:
*s4kconv -F:e -n *.s4k*

15.4 ERROR CODES S4KCONV

1001	There is no support for converting this electrode layout
1002	There is no support for converting this type of data
1003	A general conversion error occurred
1004	Geometry file does not exist or is invalid

16 APPENDIX G. AMP FILE FORMAT

This is a description of the ABEM Multi-purpose Protocol data format contained in an ASCII text file. It is intended to be fairly complete, but has the potential to have items added in the future. In order to make reading of this format easy it follows some basic guidelines that will be described below, see Section 0. In Section 0 some examples are provided.

The suggested filename extension is: *.AMP*

16.1 BASIC PRINCIPLES

- The file is divided into three sections: header, data and topography. The topography section is optional.
- The line and column numbering starts with line 1 and column 1.
- The header lines start at column 1 with a key text string that ends with a colon. The corresponding parameter starts at column 33. If two parameters or more are stated in a header line they are white space separated (one or more white spaces).
- The parameters in the header can be divided into two categories, *normal* and *information only*. The *normal* parameters have a meaning for how data are interpreted and handled, while the *information only* does not carry any special meaning needed to use the data.
- The header starts with lines containing *normal* parameters. The first line of the *information only type* is "Protocol #1:".
- The line preceding the legend is always a blank line.
- An invalid, undefined, or missing value is denoted by either a dash (-) or the text string nan.
- Infinite values are denoted by the strings inf or infinity or a value with a magnitude greater than 1.0E+38. Both the string and the value can be signed, e.g. +inf or -inf. The string alternative is case insensitive.

16.2 DETAILS, LINE BY LINE

<i>Line 1*</i> :	The name of the original record.
<i>Line 2*</i> :	Instrument model and serial number. The serial number is optional.
<i>Line 3*</i> :	Date and time of creation of the original data record in the format DD/MM/YYYY HH:MM:SS. The month can either be in a two-digit number format or a three-letter abbreviation. For example: 17th of September 1997 would be either <i>17/09/1997</i> or <i>17/SEP/1997</i> .
<i>Line 4*</i> :	X, Y, and Z co-ordinates of the base station (in meters).
<i>Line 5*</i> :	Number of text lines contained in the header section (=N _H), data section (=N _D), and topography section (=N _T) respectively.
<i>Line 6*</i> :	Acquisition mode, where 1 = SP, 2 = Resistivity, 3 = IP (single time window), 4 = IP (multiple time windows).

	If the mode is <i>2R</i> the data values are resistance values (measured in ohms)
<i>Line 7*</i> :	Measurement method. This may be any suitable text describing how the data were acquired, preferably one word. For example: Section, Sounding etc.
<i>Line 8*</i> :	Electrode layout. It comprises one, two, or three values. The second and third parameters are optional. The first parameter is an integer code, the second is the name of the layout as a text string and the third parameter defines a three-letter abbreviation. For a list of valid codes see table a: available electrode layout codes, names and three-letter abbreviations. (Page 117)
<i>Line 9*</i> :	Co-ordinate type. Can be <i>Index</i> or <i>XYZ[:[0/1/2/3]]</i> .
<i>Line 10*</i> :	Smallest electrode spacing in meters.
<i>Line 11*</i> :	Data defining marine (underwater) surveys. There four parameters; resistivity of the water layer, thickness of the water layer relative the local datum, left and right limits of water layer (e.g. when crossing a river). In a normal measurement (i.e. on-shore) there are dashes in the positions for the marine survey data.
<i>Line 12-19:</i>	Protocol #1-#8. Names of the protocols used to control the measurements. Usually used in connection with multi-electrode switch systems.
<i>Line 20:</i>	Operator.
<i>Line 21:</i>	Client.
<i>Line 22-25:</i>	Comment #1-#4.
<i>Line 26*</i> :	Blank line.
<i>Line 27*</i> :	Legend. This line describes the items in the datelines.
<i>Line N_H + 1 to N_H + N_D:</i>	Data.

NOTE! In future extensions of the data format new items may be added after line 11. In this case the line numbers for lines 12-27 will be incremented accordingly.

*) The files marked with an asterisk must always be defined in the file header.

16.3 HEADER

Index coordinate type

This type comprises three parameters; transmitter index (Tx), receiver index (Rx) and spacing multiplier index (Dx). They denote multiples of the smallest electrode spacing. If any of these indices is invalid or not defined for a certain array it will be set to 0 (zero). In the case of two indices being identical, they will have equal values.

Tx: Location of the leftmost transmitting electrode, except for the gradient array and potential (SP) measurements, where it is the leftmost moveable receiving electrode.

Rx: Number of electrode spacings between the rightmost transmitting electrode and the leftmost receiving electrode.

For reversed pole-dipole arrays (i.e. the transmitting moving electrode is located

to the right of the receiving dipole) this will be a negative number. For the Wenner array it is identical to the spacing multiplier index. For the Schlumberger array it is the number of electrode spacings between the outer and inner electrodes.

Dx: The spacing multiplier index applies to gradient, dipole-dipole, and pole-dipole arrays and defines the electrode spacing. For example, in dipole-dipole arrays it is the dipole size (AB and MN) measured in number of electrode spacings. It is also used, if needed, for potential (SP) measurements to define the receiving electrode spacing.

For Wenner and Schlumberger arrays it is the number of electrode spacings between the two center electrodes.

XYZ:[0/1/2/3]

When this type is defined, the X, Y, Z co-ordinates of the A, B, M, and N electrodes are used in the following order:

$A_x, A_y, A_z, B_x, B_y, B_z, M_x, M_y, M_z, N_x, N_y, N_z.$

XYZ co-ordinates are normally given in meters. If XYZ:0 is defined, however, the co-ordinates are given in station numbers. In the other cases 1 denotes that only X co-ordinates are listed, 2 that X and Y co-ordinates are listed and 3 that X, Y, and Z co-ordinates are listed.

16.4 DATA

There are two parameters that affect the data rows; the acquisition mode determines the format of the measured values and co-ordinate type determines the format of the electrode positions. In general, the data comes in the form:

”Data no.” ”Time” ”Electrode positions” ”Measured values”.

”Data no.” is just an ordering number of the data. It is possible to attach one or more symbols to the end of the number to represent the status of the data (see the table below for more information).

Symbol	Description
-	The data point was skipped and does not contain any information.
?	There might have been a drop in the transmitted current. Please check the data.
!	A general error occurred during data acquisition. Data may be invalid.
^	Overflow during data acquisition.
~	The data point was skipped due to current transmission failure.

The status symbols and their meaning

An example:

.
.
.
114
115?
116?
117

118
 119
 120-
 121-~
 122-~
 123-
 .
 .
 .

”Time” is the elapsed time in seconds between the creation of the original data record and the acquisition of the data point.

”Electrode positions” can be either in the *Index*-format or the *XYZ*-format described above.

”Measured values” depends on acquisition mode as follows (and in the order indicated):

1. SP: {V E}
 {Voltage (V) Error (%)}
2. Resistivity: {I V E}
 {Current (mA) Voltage (V) Apparent resistivity (Ω m) Error (%)}
3. IP (single time window): {I V_p R_a T_{on/off} T_D T C_a E}
 {Current (mA) Voltage (V) Apparent resistivity (Ω m) Time On/Off (sec) Delay (sec) Integration time (sec) Apparent chargeability (msec) Error (ms)}
4. IP (multiple time windows): {I V_p R_a T_{on/off} T_D T₁ C_{a1} T₂ C_{a2} T₃ C_{a3} . . . T_n C_{an} E}
 {Current (mA) Voltage (V) Apparent resistivity (Ω m) Time On/Off (sec) Delay (sec) Integration time #1 (sec) Apparent chargeability #1 (msec) Integration time #2 (sec) Apparent chargeability #2 (msec) Integration time #3 (sec) Apparent chargeability #3 (msec) . . . Integration time #N (sec) Apparent chargeability #N (msec) Error (ms)}

NOTE! There is one exception to the above rule. The electrode layouts with codes -1 and 0 (*Untitled* and *Resistance*) force the co-ordinate type to *XYZ* and replace apparent resistivity with resistance.

16.5 TOPOGRAPHY

The number of lines containing topography data is given in the header (line 5) and the first line containing topography data is line N_H+N_D+1.

There are two different ways of presenting the topography information.

General Topography Information

The data are given in a whitespace separated *XYZ* format. The first co-ordinate should be the location of the first electrode. The rest of the co-ordinates, however, do not necessarily have to be bound to the electrode locations. The co-ordinates need not be sorted.

An example:

-40	0	5.5
-20	0	6.5
0	0	6.0
50	0	4.8
150	0	3.0

Table A: Available electrode layout codes, names and three-letter abbreviations.

Code	Name ¹⁹	Three-letter abbreviation ²⁰	Comment
-1	Untitled	XXX	This code is used for layouts that have not been defined or arbitrary layouts. See also code=11.
0	Resistance	RES	Plain resistance, ignore electrode locations.
1	Wenner-a	WNA	
2	Wenner-b	WNB	
3	Wenner-g	WNG	
4	Pole-Pole	PPE	
5	Dipole-Dipole	DDP	
6	Pole-Dipole	PDP	
7	Square-a	SQA	
8	Square-b	SQB	
9	Square-g	SQG	
10	Schlumberger	WSC	The three letter abbr. stands for "Wenner-Schlumberger".
11	Other surface array	GN4	General four electrode array. If two or three electrodes are used set the other electrodes to "infinity".
12	Tomography	TOM	
13	Equatorial Dipole-Dipole	EDD	
14	Potential	POT	Used for SP measurements.

¹⁹These names are based on usage of 7-bit ASCII code. Thus -a, -b, and -g are used to denote $-\alpha$, $-\beta$, and $-\gamma$ respectively.

²⁰The three letter abbreviations are at this stage only a proposal, but are included so that should they become a standard, they are supported. Therefore they are optional in this edition of the data format.

16.7 EXAMPLES

Example A: An example of a data file containing IP data acquired using SAS 1000 / 4000 + ES464 LUND

```

Filename:                LI00003.S4K
Instrument ID:           SAS 4000
Date & Time:            05/05/1997 10:31:10
Base Station:           0.0          0.0          0.0
Rows header/data/topography: 27          270          0
Acquisition mode:      3
Measurement Method:    Section
Electrode layout:      1 Wenner-a
Co-ordinate type:      Index
Smallest electrode spacing: 2.000000
Marine survey:         -
Protocol #1:           WENNER_L
Protocol #2:           WENNER_S
Protocol #3:           -
Protocol #4:           -
Protocol #5:           -
Protocol #6:           -
Protocol #7:           -
Protocol #8:           -
Operator:
Client:
Comment #1:
Comment #2:
Comment #3:
Comment #4:
    
```

No.	Time	Tx	Rx	Dx	I (mA)	Voltage (V)	App.R. (ohmm)	T(On)	T(O)	T(N)	App.Ch. (ms)	Error (%)
1	971	-40	24	24	200	0.061783	93.166584	1.000	0.010	0.200	0.080724	-53.033009
2	990	-38	24	24	200	0.055621	83.875082	1.000	0.010	0.200	-2.062340	-54.997192
3	1009	-36	24	24	200	0.063124	95.188382	1.000	0.010	0.200	-1.659207	-35.355343
4	1028	-34	24	24	200	0.076727	115.701262	1.000	0.010	0.200	-1.365044	-7.856742
5	1047	-32	24	24	200	0.080722	121.725726	1.000	0.010	0.200	-3.151035	-70.710678
6	1066	-40	20	20	200	0.063699	80.046623	1.000	0.010	0.200	-0.535476	-6.862929
7	1088	-38	20	20	100	0.027652	69.497576	1.000	0.010	0.200	-1.803617	-101.015259
8	1108	-36	20	20	200	0.049046	61.632693	1.000	0.010	0.200	-7.067369	-4.714045
9	1127	-34	20	20	200	0.056467	70.958730	1.000	0.010	0.200	-1.324859	-32.635700
10	1146	-32	20	20	200	0.048668	61.157926	1.000	0.010	0.200	-4.662757	0.000000
11	1165	-30	20	20	200	0.059255	74.462229	1.000	0.010	0.200	-0.799598	-5.656854
12	1185	-28	20	20	100	0.034352	86.334918	1.000	0.010	0.200	-2.032617	-7.443229
.
.
.
258	8359	17	1	1	200	4.541188	285.331236	1.000	0.010	0.200	7.916800	16.098215
259	8389	-18	1	1	100	3.224135	405.156731	1.000	0.010	0.200	4.530084	2.351068
260	8411	-15	1	1	100	5.236955	658.095207	1.000	0.010	0.200	3.747487	0.107381
261	8441	-12	1	1	200	0.000000	0.000000	1.000	0.010	0.200	5.618462	22.609901
262	8470	-9	1	1	200	5.089408	319.776943	1.000	0.010	0.200	6.336401	4.318378
263	8499	-6	1	1	200	7.423481	466.431115	1.000	0.010	0.200	11.886886	10.709951
264	8529	-3	1	1	200	8.690695	546.052483	1.000	0.010	0.200	8.741027	14.206529
265	8559	0	1	1	50	3.441935	865.052609	1.000	0.010	0.200	6.508956	8.844142
266	8590	3	1	1	50	9.975839	2507.201668	1.000	0.010	0.200	13.477847	9.588460
267	8622	6	1	1	100	9.544613	1199.411429	1.000	0.010	0.200	0.000000	18.253386
268	8652	9	1	1	200	0.000000	0.000000	1.000	0.010	0.200	5.657914	27.452284
269	8683	12	1	1	100	1.989075	249.954547	1.000	0.010	0.200	5.712136	22.407339
270	8705	15	1	1	50	0.402264	101.099904	1.000	0.010	0.200	-13.452191	-49.913418

ABEM Terrameter SAS 1000 / 4000

Example B: Same as example a, but with XYZ-format instead of indexed co-ordinates.

```

Filename:          LI00003.S4K
Instrument ID:     SAS 4000
Date & Time:      05/05/1997 10:31:10
Base station:     0.0      0.0      0.0
Rows header/data/topography: 27      270      0
Acquisition mode: 3
Measurement method: Section
Electrode layout: 1 Wenner-a
Co-ordinate type: XYZ
Smallest electrode spacing: 2.000000
Marine survey:   -      -      -
Protocol #1:     WENNER_L
Protocol #2:     WENNER_S
Protocol #3:     -
Protocol #4:     -
Protocol #5:     -
Protocol #6:     -
Protocol #7:     -
Protocol #8:     -
Operator:
Client:
Comment #1:
Comment #2:
Comment #3:
Comment #4:
    
```

No.	Time	A(x)	A(y)	A(z)	B(x)	B(y)	B(z)	M(x)	M(y)	M(z)	N(x)	N(y)	N(z)	I(mA)	Voltage(V)	App.R. (ohm)	T(On)	T(O)	T(N)	App.Ch. (ms)	Error(%)
1	971	-80.0	0.0	0.0	64.0	0.0	0.0	-32.0	0.0	0.0	16.0	0.0	0.0	200	0.061783	93.166584	1.000	0.010	0.200	0.080724	-53.033009
2	990	-76.0	0.0	0.0	68.0	0.0	0.0	-28.0	0.0	0.0	20.0	0.0	0.0	200	0.055621	83.875082	1.000	0.010	0.200	-2.062340	-54.997192
3	1009	-72.0	0.0	0.0	72.0	0.0	0.0	-24.0	0.0	0.0	24.0	0.0	0.0	200	0.063124	95.188382	1.000	0.010	0.200	-1.659207	-35.355343
4	1028	-68.0	0.0	0.0	76.0	0.0	0.0	-20.0	0.0	0.0	28.0	0.0	0.0	200	0.076727	115.701262	1.000	0.010	0.200	-1.365044	-7.856742
5	1047	-64.0	0.0	0.0	80.0	0.0	0.0	-16.0	0.0	0.0	32.0	0.0	0.0	200	0.080722	121.725726	1.000	0.010	0.200	-3.151035	-70.710678
6	1066	-80.0	0.0	0.0	40.0	0.0	0.0	-40.0	0.0	0.0	0.0	0.0	0.0	200	0.063699	80.046623	1.000	0.010	0.200	-0.535476	-6.862929
7	1088	-76.0	0.0	0.0	44.0	0.0	0.0	-36.0	0.0	0.0	4.0	0.0	0.0	100	0.027652	69.497576	1.000	0.010	0.200	-1.803617	-101.015259
8	1108	-72.0	0.0	0.0	48.0	0.0	0.0	-32.0	0.0	0.0	8.0	0.0	0.0	200	0.049046	61.632693	1.000	0.010	0.200	-7.067369	-4.714045
9	1127	-68.0	0.0	0.0	52.0	0.0	0.0	-28.0	0.0	0.0	12.0	0.0	0.0	200	0.056467	70.958730	1.000	0.010	0.200	-1.324859	-32.635700
10	1146	-64.0	0.0	0.0	56.0	0.0	0.0	-24.0	0.0	0.0	16.0	0.0	0.0	200	0.048668	61.157926	1.000	0.010	0.200	-4.662757	0.000000
11	1165	-60.0	0.0	0.0	60.0	0.0	0.0	-20.0	0.0	0.0	20.0	0.0	0.0	200	0.059255	74.462229	1.000	0.010	0.200	-0.799598	-5.656854
12	1185	-56.0	0.0	0.0	64.0	0.0	0.0	-16.0	0.0	0.0	24.0	0.0	0.0	100	0.034352	86.334918	1.000	0.010	0.200	-2.032617	-7.443229
.
.
.
258	8359	34.0	0.0	0.0	40.0	0.0	0.0	36.0	0.0	0.0	38.0	0.0	0.0	200	4.541188	285.331236	1.000	0.010	0.200	7.916800	16.098215
259	8389	-36.0	0.0	0.0	-30.0	0.0	0.0	-34.0	0.0	0.0	-32.0	0.0	0.0	100	3.224135	405.156731	1.000	0.010	0.200	4.530084	2.351068
260	8411	-30.0	0.0	0.0	-24.0	0.0	0.0	-28.0	0.0	0.0	-26.0	0.0	0.0	100	5.236955	658.095207	1.000	0.010	0.200	3.747487	0.107381
261	8441	-24.0	0.0	0.0	-18.0	0.0	0.0	-22.0	0.0	0.0	-20.0	0.0	0.0	200	0.000000	0.000000	1.000	0.010	0.200	5.618462	22.609901
262	8470	-18.0	0.0	0.0	-12.0	0.0	0.0	-16.0	0.0	0.0	-14.0	0.0	0.0	200	5.089408	319.776943	1.000	0.010	0.200	6.336401	4.318378
263	8499	-12.0	0.0	0.0	-6.0	0.0	0.0	-10.0	0.0	0.0	-8.0	0.0	0.0	200	7.423481	466.431115	1.000	0.010	0.200	11.886886	10.709951
264	8529	-6.0	0.0	0.0	0.0	0.0	0.0	-4.0	0.0	0.0	-2.0	0.0	0.0	200	8.690695	546.052483	1.000	0.010	0.200	8.741027	14.206529
265	8559	0.0	0.0	0.0	6.0	0.0	0.0	2.0	0.0	0.0	4.0	0.0	0.0	50	3.441935	865.052609	1.000	0.010	0.200	6.508956	8.844142
266	8590	6.0	0.0	0.0	12.0	0.0	0.0	8.0	0.0	0.0	10.0	0.0	0.0	50	9.975839	2507.201668	1.000	0.010	0.200	13.477847	9.588460
267	8622	12.0	0.0	0.0	18.0	0.0	0.0	14.0	0.0	0.0	16.0	0.0	0.0	100	9.544613	1199.411429	1.000	0.010	0.200	0.000000	18.253386
268	8652	18.0	0.0	0.0	24.0	0.0	0.0	20.0	0.0	0.0	22.0	0.0	0.0	200	0.000000	0.000000	1.000	0.010	0.200	5.657914	27.452284
269	8683	24.0	0.0	0.0	30.0	0.0	0.0	26.0	0.0	0.0	28.0	0.0	0.0	100	1.989075	249.954547	1.000	0.010	0.200	5.712136	22.407339
270	8705	30.0	0.0	0.0	36.0	0.0	0.0	32.0	0.0	0.0	34.0	0.0	0.0	50	0.402264	101.099904	1.000	0.010	0.200	-13.452191	-49.913418

Example C: An example of a datafile containing resistivity data.

```

Filename:                LR00003.S4K
Instrument ID:            SAS 4000
Date & Time:              05/05/1997 12:57:33
Base station:             0.0          0.0          0.0
Rows header/data/topography: 27          275          0
Acquisition mode:        2
Measurement method:       Section
Electrode layout:         1 Wenner-a
Co-ordinate type:         Index
Smallest electrode spacing: 2.000000
Marine survey:            -          -          -
Protocol #1:              WENNER_L
Protocol #2:              WENNER_S
Protocol #3:              -
Protocol #4:              -
Protocol #5:              -
Protocol #6:              -
Protocol #7:              -
Protocol #8:              -
Operator:
Client:
Comment #1:
Comment #2:
Comment #3:
Comment #4:

```

No.	Time	Tx	Rx	Dx	I (mA)	Voltage (V)	App.R. (ohmm)	Error(%)
1	44	-40	24	24	200	0.136505	205.844900	157.648819
2	55	-38	24	24	200	6.584017	9928.462853	40.120365
3	66	-36	24	24	200	9.163850	13818.759699	11.142968
4	77	-34	24	24	200	4.960269	7479.909681	15.035524
5	114	-32	24	24	200	7.969791	12018.161162	12.330555
6	127	-40	20	20	200	8.394967	10549.426522	5.336802
7	142	-38	20	20	100	8.127193	20425.864992	17.772417
8	155	-36	20	20	200	4.502501	5658.009040	30.860693
9	168	-34	20	20	200	6.093730	7657.607645	7.562192
10	181	-32	20	20	200	4.018672	5050.012879	36.650208
11	194	-30	20	20	200	4.955431	6227.178231	18.102890
12	208	-28	20	20	100	2.964660	7451.004402	14.860514
.
.
.
258	3632	2	1	1	100	4.795485	602.618408	8.994401
259	3648	5	1	1	100	3.457042	434.424653	3.134221
260	3664	8	1	1	100	3.483400	437.736949	1.251520
261	3677	11	1	1	200	4.490331	282.135834	6.292008
262	3686	14	1	1	200	2.000446	125.691749	0.483040
263	3699	17	1	1	200	1.943116	122.089591	8.052369
264	3710	-18	1	1	100	3.076852	386.648630	0.491711
265	3722	-15	1	1	100	5.255373	660.409696	0.319420
266	3736	-12	1	1	200	0.000000	0.000000	2.801630
267	3744	-9	1	1	200	4.535642	284.982759	0.632914
268	3757	-6	1	1	200	4.184105	262.895066	3.002125
269	3766	-3	1	1	200	5.970642	375.146483	0.132899
270	3776	0	1	1	50	2.424126	609.249280	0.165847
271	3792	3	1	1	50	3.453999	868.084713	12.230147
272	3808	6	1	1	100	3.351758	421.194261	2.446515
273	3821	9	1	1	200	7.726032	485.440876	3.741924
274	3832	12	1	1	100	1.281213	161.002010	0.517482
275	3848	15	1	1	50	0.405052	101.800610	6.580061

Example D: An example of a file with resistance instead of apparent resistivity data and with topography data included.

```

Filename: LR00003.S4K
Instrument ID: SAS 4000
Date & Time: 05/05/1997 12:57:33
Base station: 0.0 0.0 0.0
Rows header/data/topography: 27 275 10
Acquisition mode: 2
Measurement method: Section
Electrode layout: 1 Wenner-a
Co-ordinate type: Index
Smallest electrode spacing: 2.000000
Marine survey: - - -
Protocol #1: WENNER_L
Protocol #2: WENNER_S
Protocol #3: -
Protocol #4: -
Protocol #5: -
Protocol #6: -
Protocol #7: -
Protocol #8: -
Operator:
Client:
Comment #1:
Comment #2:
Comment #3:
Comment #4:

No. Time Tx Rx Dx I (mA) Voltage(V) Res. (ohm) Error(%)
1 44 -40 24 24 200 0.136505 0.682526 157.648819
2 55 -38 24 24 200 6.584017 32.920082 40.120365
3 66 -36 24 24 200 9.163850 45.819248 11.142968
4 77 -34 24 24 200 4.960269 24.801346 15.035524
5 114 -32 24 24 200 7.969791 39.848953 12.330555
6 127 -40 20 20 200 8.394967 41.974834 5.336802
7 142 -38 20 20 100 8.127193 81.271935 17.772417
8 155 -36 20 20 200 4.502501 22.512503 30.860693
9 168 -34 20 20 200 6.093730 30.468653 7.562192
10 181 -32 20 20 200 4.018672 20.093363 36.650208
11 194 -30 20 20 200 4.955431 24.777155 18.102890
12 208 -28 20 20 100 2.964660 29.646605 14.860514
. . . . .
. . . . .
258 3632 2 1 1 100 4.795485 47.954849 8.994401
259 3648 5 1 1 100 3.457042 34.570415 3.134221
260 3664 8 1 1 100 3.483400 34.834000 1.251520
261 3677 11 1 1 200 4.490331 22.451656 6.292008
262 3686 14 1 1 200 2.000446 10.002232 0.483040
263 3699 17 1 1 200 1.943116 9.715581 8.052369
264 3710 -18 1 1 100 3.076852 30.768520 0.491711
265 3722 -15 1 1 100 5.255373 52.553734 0.319420
266 3736 -12 1 1 200 0.000000 0.000000 2.801630
267 3744 -9 1 1 200 4.535642 22.678207 0.632914
268 3757 -6 1 1 200 4.184105 20.920525 3.002125
269 3766 -3 1 1 200 5.970642 29.853209 0.132899
270 3776 0 1 1 50 2.424126 48.482517 0.165847
271 3792 3 1 1 50 3.453999 69.079987 12.230147
272 3808 6 1 1 100 3.351758 33.517574 2.446515
273 3821 9 1 1 200 7.726032 38.630157 3.741924
274 3832 12 1 1 100 1.281213 12.812133 0.517482
275 3848 15 1 1 50 0.405052 8.101035 6.580061
-40.00 0.00 1.60
-30.00 0.00 1.85
-20.00 0.00 2.13
-10.00 0.00 2.01
0.00 0.00 1.75
10.00 0.00 -1.30
20.00 0.00 -1.65
30.00 0.00 -0.47
40.00 0.00 0.12
50.00 0.00 2.50

```

17 APPENDIX H. ERIGRAPH FILE FORMATS

17.1 INTRODUCTION

Erigraph is primarily designed to facilitate graphical presentation of CVES data (2D DC resistivity surveying) and associated inverted model sections. The measured apparent resistivities can be plotted as pseudosections in colour or grey scale. Inverted sections can be plotted as continuous (smooth) plots or as rectangular blocks. 2D inversion must be carried out using a separate inversion program, such as for example Res2dinv.

17.2 PSEUDOSECTION PLOTTING AND FILE FORMAT

The apparent resistivity data can be stored either in a conventional ASCII format with one set of x, a, rho-a on each line or in the format used by Res2dinv (in both cases DAT filename extension is assumed). For the latter format please refer to the manual of Res2dinv. Field data files from the ABEM Lund Imaging System can be converted into DAT-files using ERIGRAPH or the Terrameter SAS1000 / SAS4000 Utility Software.

In addition to the .DAT file the program searches for a file with .INF extension, which holds information in the following format:

```

comment string
date of measurement
array type
blank           (line contents not used)
direction label left side (optional)
direction label right side (optional)
n1 no of marker labels (optional)
x[1] flag[1] marker text string[1] label distance, type flag, text string (optional)
x[2] flag[2] marker text string[2]
...
x[n1] flag[n1] marker text string[n1]

```

The topography can be automatically incorporated in the DAT file, if it is saved in an ASCII file in the same directory as the OHM file to be converted. The topography file should have the same filename as the data but with ALT extension. The file format is as follows:

```

x(1) alt(1)
x(2) alt(2)
...
...
x(n) alt(n)

```

17.3 INVERTED MODEL PLOTTING AND FILE FORMAT

Erigraph can plot inverted models in RHO-files (ASCII files) with the following format:

```

RHO-1 [IP]
nd Depth(1) Depth(1) ... Depth(nd)
x(1) rho(1,1) rho(1,2) ... rho(1,nd) [ip(1,1) ip(1,2) ... ip(1,nd)]
x(2) rho(2,1) rho(2,2) ... rho(2,nd) [ip(2,1) ip(2,2) ... ip(2,nd)]
...
...
x(nx) rho(nx,1) rho(nx,2) ... rho(nx,nd) [ip(nx,1) ip(nx,2) ... ip(nx,nd)]
/Model residuals:
[optional]
/Inversion type header:
[optional]
/IP parameter/unit
[optional]

```

The specified depth is in this case be the midpoint of each layer. Blank model cells should be entered as asterisks (*). If IP data is available it can be included as indicated, the square parantheses [] indicate that it is optional. The IP parameter/unit line would similar to the corresponding line in the DAT files.

Alternatively the RHO-2 format can be used:

```
RHO-2 [IP]
x(1) alt(1)
nd(1)
rho(1,1) Depth(1,1) [ip(1,1)]
rho(1,2) Depth(1,2) [ip(1,2)]
...
rho(1,nd-1) Depth(1,nd-1) [ip(1,nd-1)]
rho(nd) [ip(nd)]
x(2) alt(2)
nd(2)
rho(2,1) Depth(2,1) [ip(2,1)]
rho(2,2) Depth(2,2) [ip(2,2)]
...
rho(2,nd-1) Depth(2,nd-1) [ip(2,nd-1)]
rho(2,nd) [ip(2,nd)]
...
...
...
x(nx) alt(nx)
nd(nx)
rho(nx,1) Depth(nx,1) [ip(nx,1)]
rho(nx,2) Depth(nx,2) [ip(nx,1)]
...
rho(nx,nd-1) Depth(nx,nd-1) [ip(nx,nd-1)]
rho(nx,nd). [ip(nx,nd)]
/Model residuals:
[optional]
/Inversion type header:
[optional]
/IP parameter/unit
[optional]
```

The RHO-2 format has been added since it is advantageous in cases with strong gradients in the topography. The depth is in this case the bottom of each layer. There is a built-in RHO-2 format conversion tool in Erigraph for conversion from XYZ files saved by Res2dinv (do not use negative depths). This conversion tool is only designed for models inverted with topography.

For both model formats an unlimited number of comment lines may be added at the end of the file, where each comment line should start with a slash (/). This can be useful for saving information on e.g. inversion parameters together with the model.

Res2dinv has an option for exporting inverted models in Lund-format, which will in the present version use the old version of the RHO-1 format. In some versions of Res2dinv there is a bug so it will export non-sense models.

17.4 TOPOGRAPHY

If a data file is opened and an associated inverted model is plotted selecting "2D section", the models will be plotted with topography provided the DAT-file contains topography (please consult the Res2dinv manual for details). Alternatively, the topography may be saved in a file with ALT extension (see above). However, in any case it is necessary to open a datafile and then plot the associated 2D section since the RHO-1 model file does not contain any topography information. The RHO-2 format includes topography in the model file.

17.5 USER DEFINED TEXT

The text strings on the axes of the diagrams can be customised by placing a text file in the directory holding the data files to be plotted. This can be handled automatically via the menu “Settings/Diagram Labels”.

For the pseudosections the file must be named PSEUDO.TXT and have the following structure:

```
Header
Distance label
Electrode spacing label
Apparent resistivity legend label
```

Example of a PSEUDO.TXT file:

```
PSEUDOSECTION
Distance/[m]
a/[m]
Apparent resistivity/[ohm-m]
```

For the model sections the file must be named MODSEC.TXT and have the following structure:

```
Header
Distance label
Depth scale label
Topography scale label
Resistivity legend label
```

Example of a MODSEC.TXT file:

```
2D INVERTED SECTION
Distance/[m]
Depth/[m]
Level/[m]
Resistivity/[ohm-m]
```

17.6 LEVEL MARKERS

Level marks can be included in the model plots by saving the level marker data in an ASCII file with MRK extension in the data/model directory. Use the following format:

```
"comment" "comment" / first marker line
x(1,1) depth(1,1)
x(1,2) depth(1,2)
...
...
x(1,n) depth(1,n)
"comment" "comment" / second marker line
x(2,1) depth(2,1)
x(2,2) depth(2,2)
...
...
x(2,n) depth(2,n)
```


17.7 REFERENCE DATA

Drilling reference data can be included in the model plots as well.

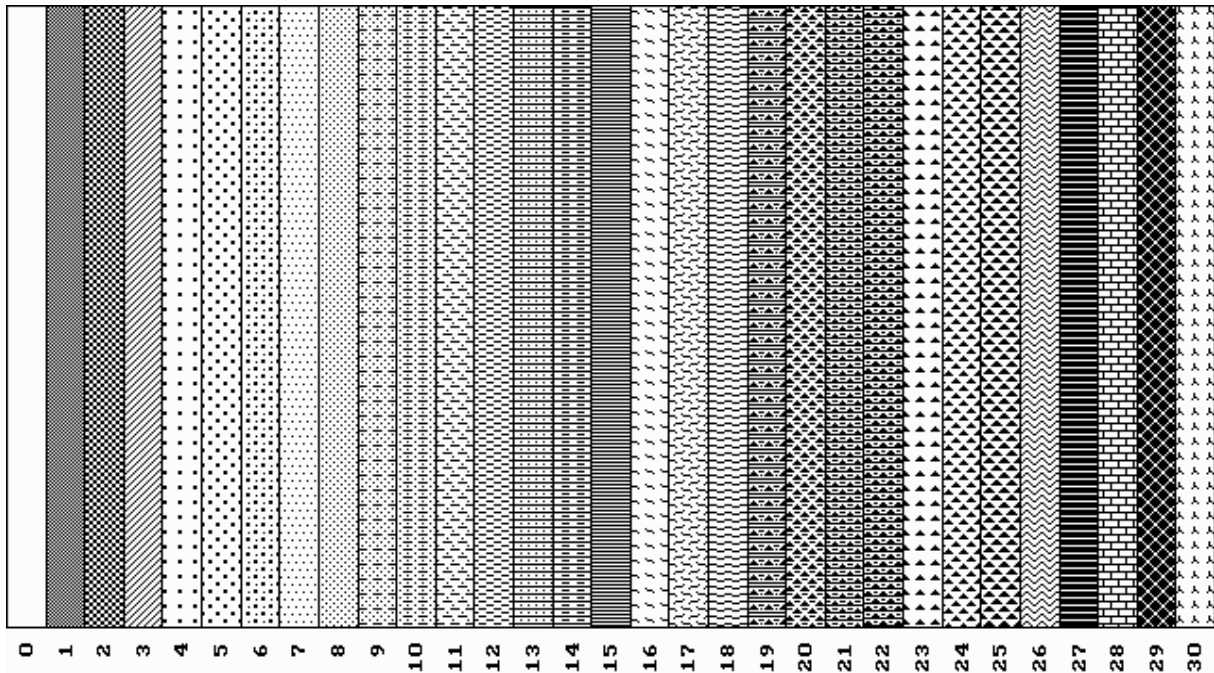
```

x(1) / distance
id(1) / reference point id text string (optional)
gwl(1) / groundwater level (optional)
n1(1) / no of layers
x(1,1) d(1,1) code(1,1) col(1,1) txt(1,1) / dist, depth, materialcode, textcolour,
text label
x(1,2) d(1,2) code(1,2) col(1,2) txt(1,2)...
...
x(1,n1) d(1,n1) code(1,n1) col(1,n1) txt(1,n1)
x(2) / distance
id(2) / reference point id text string (optional)
gwl(2) / groundwater level (optional)
n1(2) / no of layers
x(2,1) d(2,1) code(2,1) col(2,1) txt(2,1) / dist, depth, materialcode, textcolour,
text label
x(2,2) d(2,2) code(2,2) col(2,2) txt(2,2)...
...
x(2,n1) d(2,n1) code(2,n1) col(2,n1) txt(2,n1)

```

The text strings for the layer materials are written in black if the text colour is set to 0, and white is set to 1 (in the latter case select transparent labels under “Settings/Plot Options/Transparent layer labels” in order to see the text).

The following fill patterns are available for plotting the layers, with the corresponding material codes below:



18 APPENDIX I. TECHNICAL SPECIFICATIONS

This section presents specifications for the Terrameter SAS 1000 / 4000, the Electrode Selector ES464 / ES10-64eC / ES10-64C and the Terrameter SAS LOG 300.

18.1 TERRAMETER SAS 1000 / 4000 - SPECIFICATIONS

Transmitter

Automatic or user selectable currents	1, 2, 5, 10, 20, 50, 100, 200, 500, 1000 mA
Excitation voltage (max)	400 V (800 V peak-peak)
Output power, max	100 W at 50% duty cycle
Accuracy of transmitted current	Better than 0.5%
Current pulse length	0.1 sec to 4 sec
Cycle type in resistivity mode	plus-minus-minus-plus (commutated DC)
Cycle type IP mode	plus-zero-minus-zero (commutated DC)

Receiver

Self Potential (SP)

Number of input channels	4, galvanic isolated (SAS 1000 one channel)
Input impedance	10 M Ω , min
Automatic ranging	± 250 mV, ± 10 V, ± 400 V
Resolution	1 μ V (at 0.5 sec integration time)
Accuracy (at 0.5 sec integration)	Better than 0.2% measured at 100 mV, 5 V and 200 V
Precision (at 0.5 sec integration)	Better than 0.1% measured at 100 mV, 5 V and 200 V
Dynamic range	up to 140 dB plus 64 dB automatic gain

Resistivity

Number of input channels	4, galvanic isolated (SAS 1000 one channel)
Input impedance	10 M Ω , min
Automatic ranging	± 250 mV, ± 10 V, ± 400 V
Resolution (theoretical)	1 μ V
Accuracy $\Delta V/I$ (at 0.5 sec integration)	Better than 1% measured at 1 Ω , from 1 mA to 1000 mA with varying resistive load from 0 to 380 k Ω .

Precision $\Delta V/I$ (at 0.5 sec integration)	Typically better than 0.5%
Dynamic range	Up to 140 dB plus 64 dB automatic gain
Induced Polarization (IP)	
Number of input channels	4, galvanic isolated (SAS 1000 one channel)
Input impedance	10 M Ω , min
Automatic ranging	± 250 mV, ± 10 V, ± 400 V
Resolution (theoretical)	1 μ V
Type of IP measurements	Time domain chargeability (M) measured in <i>msec</i>
Initial time delay	10 ms up to 10 sec in steps of 10 ms
Number of IP time intervals	1-10 user defined time windows on all channels.
Basic integration interval	20 msec or 16.67 msec depending on power line freq.
Dynamic range	Up to 140 dB plus 64 dB automatic gain
General	
Computer	PC compatible
Memory capacity	> 1 000 000 data points
Temperature range, operation	-5°C to +50°C
Casing	Waterproof (IP66), rugged cast aluminum
Display	LCD, 200x64 pixels, 8 lines of 40 characters
Multi connector	Current and potential for all four channels. RS232 serial communication with PC or external devices.
Support for external devices	LUND Imaging System, SAS LOG 300, Multimac
Power	An ordinary car battery is recommended. NiMH clip-on power pack (optional accessory) could be used in low current soundings.
Power consumption	1000 mA in standby. Up to 20 A during transmission of high currents.
Weight	4.6 kg. (SAS EBA 1.2 kg, NiMH Power Pack 2.0 kg)
Dimensions	105 x 325 x 300 mm (W x L x H) with power pack

18.2 ELECTRODE SELECTOR ES464 - SPECIFICATIONS

Number of channels	4x64 channels standard configuration. Up to four units of Electrode Selector ES464 can be linked together via the serial port, giving e.g. 4x256 channels.
Power supply	12 V DC clip-on re-chargeable battery or an external battery via an adapter (operates several days on a charged battery).
Operating temperature	-10° C to +70° C.
Casing	Waterproof (IP66), rugged cast aluminum
Dimensions	W x L x H: 105 x 325 x 300 mm.
Weight	6.7 kg (including battery pack).
Resistivity instrument	The Lund Imaging System requires an ABEM Terrameter SAS 1000 / 4000 (or SAS 300C and PC).

18.3 ELECTRODE SELECTOR ES10-64C - SPECIFICATIONS

Number of channels	10x64 channels standard configuration (4x64 channels for model ES10-64C). Several units of Electrode Selector ES10-64C can be linked together, giving e.g. 10x256 channels. The electrode selector is also available in a single channel version called ES10-64eC.
Power supply	12 V DC power supply via SAS1000 / 4000 (negligible extra power consumption).
Operating temperature	-10° C to +70° C.
Casing	Waterproof (IP66), rugged cast aluminum
Dimensions	W x L x H: 120 x 300 x 200 mm.
Weight	5.2 kg
Resistivity instrument	The Lund Imaging System requires an ABEM Terrameter SAS 1000 / 4000.

18.4 TERRAMETER SAS LOG 300 - SPECIFICATIONS

Cable length		300 m
Logging probe diameter		40 mm
Survey modes	16" short normal	0.05 - 100 000 Ω m
	64" long normal	0.5 - 100 000 Ω m
	18" lateral	0.5 - 100 000 Ω m
	Fluid resistivity	0.05 - 100 000 Ω m
	Self Potential	0.05 - 1000 V
	Temperature, range	0°C ... +50°C
	Temperature, precision	0.01°C (0°C ... +20°C)
	Temperature, precision	0.1°C (20°C ... +50°C)
	Temperature, accuracy	1°C
Weight		14.0 kg
Dimensions		880x440x230 mm
Power supply		Powers from SAS 1000 / 4000

19 APPENDIX J. REMOTE CONTROL

This is a description of the commands used for remote control of Terrameter SAS1000 / 4000.

19.1 COMMUNICATION PARAMETERS

The following setup is used:

Baudrate	Selected in SAS4000 Main Menu. (Default: 115200).
Databits	8
Stopbits	1
Parity	None
Handshaking	DTR, DSR

19.2 COMMANDS AND SYNTAX

All commands consists of a three letter (upper case) combination, an optional list of parameters (separated from the command by a space) and ends with a '!'. If there are more than one parameter in the list they are comma-separated. The command will not be executed until the '!' is received.

When the connected Terrameter SAS4000 starts executing a command, it transmits the character '#' (ASCII decimal code 35).

19.2.1 Delete

DEL filename(s)

Deletes the specified file(s). Most system files cannot be deleted. Wildcards are not allowed.

19.2.2 Dir

DIR path

Returns a directory listing of the specified path.

19.2.3 Exit

EXT

Exits the program.

19.2.4 Install Software

INS filename

Installs the file called *filename* in the root directory. Wildcards are not allowed in the parameter, the file must be present in the current directory and have the extension .EXE.

19.2.5 Send Serial Number

GID

Returns a character string containing the serial number of the connected SAS4000. For example:

4981663

19.2.6 Send Version String

VER

Returns a character string containing the name of the application, its version and revision number. For example:

Remote Control Version 1.23 Rev.A

19.2.7 Set Date And Time

STM [yyyy/mm/dd hh:mm:ss]

Set (or get) the real-time clock's date and time.

yyyy: Year (1980-2048).

mm: Month (1-12).

dd: Day.(1-31).

hh: Hours (0-24).

mm: Minutes (0-59).

ss: Seconds (0-59).

19.2.8 Set Default

DFL

Reset all parameters to their default values. Disables measurements.

19.2.9 Set Error Checking

SEC [*err4, err5, algorithm, speed*]

This command sets (or gets) the measurement error checking parameters and the output setup algorithm and speed parameters.

- err4: Check error 4? 0=No, 1=Yes.
- err5: Check error 5? 0=No, 1=Yes.
- algorithm: Select the algorithm for setting up current output. 0=Safe mode, 1=Smart mode.
- speed: Select the speed for setting up current output. 0=Slow, 1=Medium, 2=Fast.

19.2.10 Set IP

STI [*I_{mA}, I_{mode}, f_s, t_{On/Off}, t_D, t_{0(index)}, mult, N*]

- I_{mA}: Output current (mA). Valid range: 1-1000.
- I_{mode}: Output current mode. Valid values: 0 = automatic ranging, 1 = fixed current.
- f_s: Sampling frequency (Hz). It should be set in accordance with power line frequency that can exist in the area where measurements are being done. Valid values: 50, 60.
- t_{On/Off}: The current switch on and switch off time (s). The on and off time are equal. Valid range: 1.0-8.0 s (in steps of 0.5 s).
- t_D: IP delay time (s). This parameter defines the time between current switch off and the start of the first integration interval. Valid range: 0.01-10.0.
- t₀: The number of samples included in the first integrating interval. Valid range: 1-50 at 50 Hz, 1-60 at 60 Hz. See Table 2 for some examples.

Table 2 The integration interval indices and the corresponding times at the two sampling frequencies.

Integration Time	t ₀ (f _s = 50 Hz)	t ₀ (f _s = 60 Hz)
16 2/3 ms	N/A	1
20.0 ms	1	N/A
100.0 ms	5	6
200.0 ms	10	12
500.0 ms	25	30
1000.0 ms	50	60

- mult: Multiplication factor. Valid values: 1, 2.

N: Number of integration intervals. Valid range: 1-10.

If no parameter list is defined the current parameter values are returned in a text string with the same format.

If the multiplication factor (*mult*) equals one, each IP interval's integration time will be equal to t_0/f_s . If the multiplication factor is equal to two, the length of each successive IP interval will be doubled, i.e. if the first interval is 100 ms the second will be 200 ms the third 400 ms and so on. The total integration time, however, cannot exceed 8 seconds.

19.2.11 Set Mode

OPM [mode]

Sets the measurement mode. The valid parameter values are listed in Table 2. If no parameter is given, the current mode is returned. The mode selected is active until another mode is selected or the program is terminated.

Table 3 Valid measurement mode parameters.

Mode	Description
0	Disables measurements
1	SP
2	Resistivity
3	IP

19.2.12 Set Resistivity

STR [I_{mA}, I_{mode}, f_s, t_D, t_{Acq}]

Sets the parameters specific for resistivity measurements.

I_{mA}: Output current (mA). Valid range: 1-1000.

I_{mode}: Output current mode. Valid values: 0 = automatic ranging, 1 = fixed current.

f_s: Sampling frequency (Hz). It should be set in accordance with power line frequency that can exist in the area where measurements are being done. Valid values: 50, 60.

t_D: The delay time between current switch on and start of sampling. Valid values 0.0-4.0 s (in steps of 0.1 s)

t_{Acq}: The time used for sampling (integration). Valid values 0.1-4.0 s (in steps of 0.1 s).

If no parameter list is defined the current parameter values are returned in a text string with the same format.

The total time for one single measurement pulse will be equal to $4 * (t_D + t_{Acq})$ seconds.

19.2.13 Set SP

STS [t]

t: The measure time in seconds. Valid values 0.1-8.0 s (in steps of 0.1 s).

If no parameter list is defined the current parameter value are returned in a text string with the same format.

19.2.14 SetStack

SAS [N_{min} N_{max} E_{limit} Norm]

N_{min}: The minimum number of stackings.

N_{max}: The maximum number of stackings.

E_{limit}: The error limit that ends stacking (in percent). Valid values 0.5-100 (in steps of 0.5).

Norm: Norm used to sum the stacked values. Can be 0 or 1, where 0=median and 1=mean.

This command sets the limits for the automatic stacking. N_{min} must be less than, or equal to N_{max}. If N_{min} is less than N_{max} the stacking will be finished if the measurement error becomes less than E_{limit}.

If no parameter list is defined the current parameter values are returned in a text string with the same format.

19.2.15 Sound

SND [freq, freq, freq.]

This command sounds a tone with a pitch corresponding to *freq* (*freq*=100 lowest pitch, *freq*=20000 highest pitch). There is one tone for each parameter passed.

19.2.16 Contact Test

TST

This command performs a contact test by trying to transmit a current. If a valid measure mode has been set, it returns the current transmitted. If a current could not be transmitted, a zero is returned.

19.2.17 Trig

TRG

Triggers a measurement. When the command has been accepted and the measurement started a '!' is returned. Then you have to wait for the data to arrive (or an error code). The data are returned in the following format:

CHX I,V,E,N[,C_{ip1},E_{ip1},C_{ip2},E_{ip2}, ... ,C_{ipn},E_{ipn}];

where X=channel number, I=output current (mA), V is the measured voltage in volts (the primary voltage in IP measurements), E is the normalized error (standard deviation) in percent and N is the number of stackings. When doing IP measurements some additional pairs of data are returned. The number of pairs is equal to the number of IP intervals and each pair consists of the apparent chargeability for that interval (in milliseconds) and the measurement error (true error in milliseconds). After each channel's data has been returned a ';' and a new line are returned to mark end of data.

The time you have to wait before data starts coming from the instrument depends on the type of measurement, cycle time, integration time etc.