DUALEM-1H

User's Manual

DUALEM Inc. www.dualem.com

Introduction

DUALEM sensors measure terrain conductivity, detect shallowly buried objects of high conductivity and, where conductivity is negligible, measure the magnetic susceptibility of terrain.

DUALEM sensors can be applied to many types of shallow-earth investigations. These include soil mapping and monitoring, archaeology, the delineation of conductive contamination, and exploration for groundwater and clay. Electrically resistive targets at surface, such as aggregates, soil frost and tar pits, often are delineated successfully. Buried resistors such as voids and complex features such as hydrocarbon contamination, if detectable at all, require meticulous technique and expert interpretation. Highly conductive bodies, such as steel drums, metal tanks and iron sulfides are readily detected by DUALEM. However, interpretation by a skilled geophysicist is required to infer the depth and geometry of the feature.

Patented DUALEM sensors incorporate an EM-transmitter that operates at a fixed frequency and 1-, 2- or 3-pairs of EM-receivers. As shown in Figure 1, the transmitter and one of the receivers in a pair have horizontal windings, and these components form the horizontal co-planar geometry (HCP). The other receiver in a pair has vertical windings; it combines with the transmitter to form the perpendicular geometry (PRP).

Figure 1: DUALEM Schematic Profile.

DUALEM sensors are designed to operate within the low-frequency-approximation of EM response, as defined by J.R. Wait in *A Note on the Electromagnetic Response of a Stratified Earth: Geophysics, 27 (1962), 382-85*. Low-induction-number (LIN) and resistive-limit are synonymous with low-frequency approximation. At LIN, an electromagnetic system has stable depth-sensitivity, response amplitude is linearly proportional to conductivity, and response is essentially in quadrature to the phase of the transmitted field.

Under the assumption that DUALEM sensors will typically operate within LIN, the sensors linearly scale the quadrature component of response, in ppt of the transmitted field, into millisiemens/metre (mS/m) of apparent conductivity (ECa). (Conductivity is the inverse of resistivity, *e.g.* 1 mS/m conductivity equals 1000 ohm-m resistivity).

The relative sensitivity to the earth at LIN follows from a simplification of Wait's analysis. For PRP the sensitivity to an incremental layer in the earth is:

$$I_{PRP} = 2/(4s^2 + 1)^{3/2}$$

where s is the depth to the layer, in units of the transmitter-receiver separation.

Integrating with respect to s gives the cumulative sensitivity of the earth to the depth s:

$$C_{PRP} = 2s/(4s^2 + 1)^{1/2}$$

Similarly, corresponding formulae for HCP are:

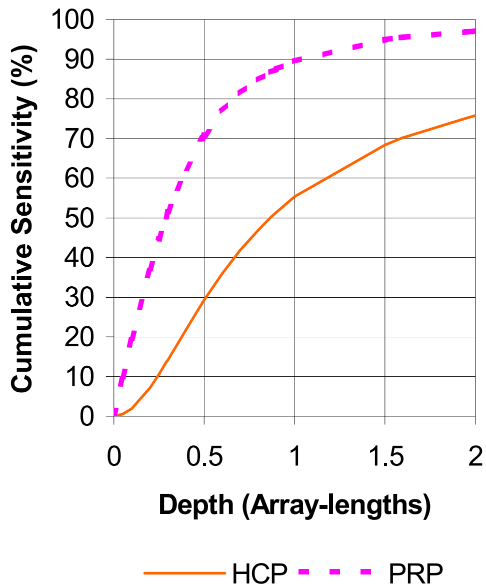
$I_{HCP} = 4s/(4s^2 + 1)^{3/2}$

where I_{HCP} is the sensitivity to an incremental layer at a depth of s separations, and:

$C_{HCP} = 1 - 1/(4s^2 + 1)^{1/2}$

where C_{HCP} is the cumulative response of the earth to depth s.

Figure 2: DUALEM Cumulative Sensitivities.



The cumulative sensitivities of PRP and HCP are plotted in figure 2. Effective depth (ED) is defined as the depth to which a transmitter-receiver array accumulates half its total sensitivity, and depth of exploration (DOE) is defined as the depth to which an array accumulates 70 % of its total sensitivity.

The sensitivity of a PRP array accumulates rapidly with depth; ED is about 0.3 array lengths, and DOE is about 0.5 array lengths.

Sensitivity of an HCP array accumulates more gradually with depth; ED is about 0.9 array lengths and DOE is about 1.6 array lengths. For reference, the table at the end of this introduction shows DOEs for the DUALEM described by this manual.

The arrays are sensitive to all the material beneath them, including the height of air between the array and the surface of the ground. Thus, when a DUALEM is carried at a given height above the ground-surface, the DOE in the earth for each array is reduced by this height. Note that the arrays are centered in the boom of the sensor, so the arrays are at a height of 4.5 cm where the sensor is on the ground.

Under strict LIN conditions, where there is negligible in-phase response from conductivity, DUALEM sensors can measure the in-phase response due to magnetic susceptibility, in ppt of the transmitted field.

As conductivity increases, the validity of LIN DOE and ECa deteriorate, and interpretation becomes complex. A greater proportion of response becomes in-phase, so LIN ECa and DOE increasingly understate, respectively, true conductivity and the sampled volume of earth. At the LIN limit, for example, ECa understates true conductivity by about 10 %; the depth of earth providing significant ECa response decreases by a similar percentage, even as the depth and breadth with significant in-phase response increases. For HCP, quadrature peaks where true conductivity is about 25-times the LIN limit. At this peak, ECa understates true conductivity by about 70 %, and further increase in true conductivity causes HCP ECa to decrease.

Interpretations of conductivity and depth can remain useful as true conductivity increases above the LIN limit, especially if the interpretations incorporate in-phase response and/or conductivity and depth information from complementary methods (*e.g.* push probe, radar, resistivity, etc.) Where buried metal or other features generate response beyond the LIN range, a DUALEM sensor continues to produce accurate and useful measurements but the interpretation of the results becomes complex.

Quadrature responds especially well to elongated conductors, such as metal pipes. Inphase becomes strong over highly conductive material, and is particularly effective for locating confined conductors, such as metal drums or boulders of graphite or sulfide. The amplitude of the response to buried metal decreases exponentially as the distance increases between the DUALEM sensor and the object. This limits the detection depth to, for example, about 2 m for a 200-L steel drum.

When using both in-phase and quadrature in the analysis of EM beyond LIN, it may be convenient to convert values in mS/m back to ppt so that the units of both in-phase and quadrature are the same. The following table shows LIN limits for the DUALEM described by this manual, as well as ppt-per-mS/m factors. Multiply values in mS/m by these factors to obtain values in ppt.

Array	0.5-m HCP	0.6-m PRP	1-m HCP	1.1-m PRP
DOE (m)	0.8	0.3	1.6	0.5
LIN Limit (mS/m)	960	9100	240	2700
ppt per mS/m	0.00455	0.0064	0.0178	0.0215

Equipment and Maintenance

Boom

The sensor boom, which holds the transmitter and receivers of the sensor in their fixed arrangement, is made to exacting specifications from a fiber/resin composite. The composite has excellent stability to minimize drift and noise. The design and strength of the composite allows the boom to be both light and durable. Nevertheless, the boom should not be subjected to shocks and stresses greater than those encountered routinely in use and shipment.

The boom protects the sophisticated electronic components of the sensor from many hazards. Typical precautions should be taken against other hazards to electronic components, such as high-energy radiation, frequent start-ups below -20 °C or prolonged exposure above +40 °C.

The end of the boom that houses the transmitter (Tx boom) has three light-emitting diodes (LEDs) and a threaded 4-pin connector at one of its ends. A common name for the connector type is AC-Micro, but there are other names such as ½-20 and microFast. The connector should be kept as clean and dry as practicable, and may be cleaned with alcohol. Lubrication is not recommended, although some users have found that contact cleaners/enhancers (e.g. Stabilant 22) improve the performance of dirty and worn connectors.

The connector is closely integrated with a complex portion of the sensor, and care should be taken not to damage it. Some users leave an AC-Micro patchcord attached to the connector whenever possible and connect other cables to the patchcord. The ground pin of the connector extends slightly beyond the other pins, so any static electricity will discharge to ground. This pin is vulnerable to bending and breaking if the cable is connected to the sensor with any twisting motion.

Controller

The Controller is an Android smartphone (with GPS) that runs the Dualem app. It communicates with the sensor by Bluetooth, and to the internet by Wi-Fi. It can also communicate and/or receive power through its USB port (with micro-USB connector).

With a full charge of its battery, the Controller will operate the Dualem app for several hours. You will maximize the time of operation if you let the app run in the background (after its display dims); there is an audio alarm if the Bluetooth connection fails. An external battery (not supplied) connected through the USB port of the Controller might extend its operation to several days before requiring recharging.

You should install the Controller in its weatherproof cover if it might otherwise get wet during use.

You login to the Dualem app with your username and password on any suitable Android device where it is installed. The app displays text received from the sensor and can send sensor-menu commands to the sensor. If you set up the sensor to output NMEA-format sentences, the app can log their information, along with GPS positioning if the device is so equipped.

The GPS outputs position once per second, so a log of completely positioned data can be obtained with measurement periods that are 1 s or longer, including manual measurements. Also, variable demands on the processor of your device can cause the loss of some measurements made at shorter measurement periods, but the app can initiate such rapid measurements for complete logging by the internal logger of sensor.

Whenever you initiate logging, the Dualem app opens a file in the DUALEM folder in device memory and adds measurements to the file until you stop logging. If the device has GPS, the measurements will be positioned; the display can also show your current position relative to the starting position, or the position of data points on Google Maps. You can upload any logged file in comma-separated-values (CSV) format to the internet.

The app can upload the data from the internal logger of the sensor, store them in a CSV file in the device memory, from where they can be uploaded to the internet. The following record, in CSV format, describes the fields of data in an uploaded file:

Time(HhMmSs),Line,LinePosition,Station,StationPosition,MeasurementNumber,1/2mHcpECa(mS/m),1/2mHcpInphase(ppt),1/2mPrpECa(mS/m),1/2mPrpInphase(ppt),Power(V),Temperature(K),Pitch(°),Roll(°),Time,1mHcpECa(mS/m),1mHcpInphase(ppt),1mPrpECa(mS/m),1mPrpInphase(ppt),XAcc(gal),YAcc(gal),ZAcc(gal),XMag(µT),YMag(µT),ZMag(µT),2ndTemperature(K)

Power Harness

The harness provides a means of powering the DUALEM sensor and carrying it on survey. The harness is assembled when originally shipped with the sensor and, with care, can be re-attached to the sensor.

There is a clamp at each end of the harness. Each clamp has a top and bottom piece that fit around the shell of the sensor, along with two bolts and four nuts to tighten the clamp to the shell. One clamp has a protrusion that protects the cable that attaches to the round connector on one end of the sensor.

If necessary, loosen the nuts on the bolts so that the shell can slide into the central hole of each clamp. Slide the clamp with no protrusion (flat clamp) over the end of the sensor that bears the DUALEM label to a point far enough along the shell that the other end of the harness can reach beyond the other end of the sensor. If you are on a surface that is fairly smooth and level, put the clamp down on the surface so that the threaded portions of the bolts (with the nuts) are at the top. If necessary, rotate the shell in the clamp so that the DUALEM label is parallel to the bottom edge of the clamp and its letters are upright. Tighten the lower nut on each bolt so that the gaps on each side of the clamp are roughly even and the nuts are finger-tight. Slide the end of the harness sewn into a loop over the end of the sensor with the DUALEM label, and along the sensor until the end is adjacent to the clamp.

At the other end of the harness, turn the clamp if necessary to remove twists from the harness straps. Orient the clamp so the threaded portions of the bolts (with the nuts) are at the top. If necessary, slide the patch-cord (yellow cable) in the sleeve so that the right-angle connector at the end of the cord is below the midpoint (i.e. gaps) of the clamp. With the protrusion away from the sensor, slide the clamp onto the shell so that the protrusion is near-or-at the end of the sensor.
With the cord extending up from the right-angle connector, carefully position the connector so that its sockets engage the pins of the connector on the sensor and gently push the connectors together. Carefully but fully tighten the threaded shell of the right-angle connector onto the threads of the sensor connector.

Ensure that the protrusion is firmly against the end of the sensor (i.e. there is no tie, etc., caught in-between), and the harness strap is in its central slot. With the bottom edge of the clamp parallel to the bottom edge of the other clamp, tighten the lower nut on each bolt so that the gaps on each side of the clamp are roughly even and the nuts are at least finger-tight. Tighten the upper nut on each bolt at least finger-tight to the lower nut.

The straight connector at the other end of the cord connects to the data/power module. The module has a holder for 8 AA batteries to power the sensor, a round connector to attach to the cord connector and a 9-socket D-subminiature connector in case you wish to connect a serial-port cable, adapter, etc., to the serial port of the sensor.

As damage to the pins of the cord connector is much easier to remedy than damage to the pins of the sensor connector, we suggest keeping the sensor connector attached to the right-angle cord connector whenever possible; you can control power with the cord-module connection or with batteries in the holder.

Pull up on the middle of the harness. If the length of the harness is not suited to your planned method of surveying, adjust the length of the harness by moving the glides on the harness straps and/or the position of the flat clamp on the shell. When the clamp is in the position you want, tighten its lower nuts, and then its upper nuts, at least finger tight.

In moderate to warm weather, 8 fresh AA batteries usually can power the sensor for a survey-day. You might find that making a pull-tag with a loop of transparent tape around each of a few of the batteries before inserting them into the holder makes it easier to remove them after use. To power the sensor, ensure that cord is connected to the module and insert the batteries into the holder. Giving the holder a few slight and gentle twists afterward can help the springs of the holder extend to improve the contacts of the batteries in the holder.

Data/Power Cable

The data cable supplied with the DUALEM sensor, with its specialized connectors, is designed to function under all reasonable survey conditions. However, at several years, the typical service-life of a cable is less than that of the sensor. The following suggestions may help to extend the serviceability of both the cable and the sensor.

In temperatures progressively below freezing, increasing care should be taken when flexing or coiling cables. At any temperature, crushing, shearing, twisting and straining the cable should be avoided, especially at the connectors. Connectors should be kept clean and dry. Cables should not be stored in strong sunlight or at high temperatures.

The cable has a 9-socket DE-9 connector at one end, and a 4-socket dual-keyway AC-micro connector at the other. The DE-9 connector attaches to a device that provides serial communication with the sensor. Power can also be supplied through the DE-9 connector or, optionally, through wires with connectors that splay from the DE-9 end of the cable. The AC-micro connector attaches to the threaded connector on the sensor. The following table shows the composition of the cable, which might be of interest if you wish to obtain cables from a source other than Dualem:

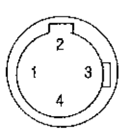


Figure 3: AC-Micro sockets

AC-Micro Socket	Wire	DE-9 Socket	Function
1	Red/Black	2	DUALEM data Tx / Logger Rx
2	Red/White	3	DUALEM data Rx / Logger Tx
3	Red	9	+ 12 V power
4	Green	5	Ground

The AC-Micro connector on the data/power cable supplied by Dualem is straight in-line with the cable to reduce twisting at the connector that can damage the setting or seal of the mating connector on the sensor. Damage caused by excessive mechanical stress is not covered by your warranty. If you use a cable with an angular bend at the connector you should take measures to reduce the possibility of twisting, such as using the clamp with the cable guide.

Provided the connection is clean and dry, the cable can be left attached to the sensor when not in use, which will minimize the number of connection cycles. Making the connection before applying power ensures that any sparking will occur on the power contacts, which are typically more robust and easier to replace.

The sensor starts operating as soon as you connect power, and stops operating as soon as you disconnect power. There are 3 LEDs by the connector on the sensor: When you connect power, the LEDs will flash red and then green to show that they are functioning.

If you apply voltage that could damage the sensor, a circuit breaker in the sensor will attempt to isolate the sensor from the voltage. If the breaker is successful in such a case, it will reset in a few minutes and allow the sensor to operate with voltage in the correct range.

The LED labeled P indicates the DC-voltage received by the sensor. If the LED is not lit, the sensor is receiving less than 3 V. If the LED is flashing green, the sensor is receiving less than 8.5 V, which is too low for reliable operation. If the LED is steady green, the sensor is receiving adequate voltage, between 8.5 V and 17 V. If the LED is amber, the sensor is receiving more than 17 V, which may harm the sensor. If the LED is red, the polarity of the voltage is opposite to what it must be for proper operation.

Communication

The sensor communicates using ASCII characters through its RS-232 serial port and its Bluetooth transceiver. You can receive measurements from the sensor, and control its operation, using any device that provides such communication.

You can use the optional DUALEM Controller to operate the sensor. The purpose-built Controller is easy to use, but it cannot display NMEA-compliant output. If you have a Controller, you can use it by connecting its cable to the AC-Micro connector on the sensor.

The LED labeled R indicates the status of the serial line on which the sensor receives commands from the device you are using to control it. Similarly, the LED labeled T indicates the status of the serial line on which the sensor transmits data to a logging device. The LEDs function when they receive adequate power from the sensor, but are otherwise independent of the sensor. If an LED is not lit, either the line is idle or the indicator is not powered. An LED will flash green when the line is transferring data (but not always for a single character at a high baud-rate). If an LED is red, the line is probably shorted; the T LED will also be red if the output circuitry is damaged. If the R LED is amber, the line is not connected or the absolute voltage on the line is less than 4 V.

The voltage on an idle serial-line is about - 6 V. If you have a voltmeter with a response time that is sufficiently fast, when there is a pulse of communication you will see the voltage increase momentarily to about + 6 V. The baud rate (bits/s) of the serial port is generally 38400, but DUALEMs that are older, have only 2-arrays and/or 1-s (or longer) measurement periods usually have a baud rate of 9600. You can change the rate using the hidden menu.

In addition to the correct port-number and baud rate, other serial-port settings are 8 for data bits, None for parity, 1 for stop bits, and None for flow control.

Many users operate sensors from devices with a display for output, memory for storing output, and keys for sending ASCII characters 1, 2, 3, 4, 5, $, % and T (or t) to the sensor. The device must run suitable communications software, such as HyperTerminal and Termite that run on Windows personal computers (PCs).

DUALEM sensors incorporate Class 2 Bluetooth (BT) hardware to communicate wirelessly using the BT-firmware Serial Port Profile (SPP). For a device to communicate with the sensor, it must have BT hardware version 2.1 (or later) with SPP. Your communicating device might be a handheld computer with BT, a PC with a BT dongle, an Android phone, etc. (iPhones and iPads cannot communicate, due to their restrictions.) If your device demands a passcode, it is 1234.

When your communicating device has established a link with the BT in your DUALEM sensor, the SPP emulates a standard RS-232 serial connection (but with a maximum baud-rate of 460k instead of 115k). The sensor sends measurements and other text to both the BT port and the serial port, so the T LED flashes. Text sent from your communicating device will have the same effect as text received through the serial port, except that the R LED will not flash.

You might find BT communication particularly useful for uploading data from the internal logger as quickly as possible, or for streaming a full complement of NMEA-compliant sentences at a high output-rate. High-rate communication might be possible over a distance of only several metres, depending on obstructions and ambient noise.

Operation

You can operate the sensor to provide output that is either NMEA-0183 compliant or in 4-line by 20-character (4x20) format. NMEA, the National Marine Electronics Association, maintains the 0183 data specification that is supported by many GPS devices.

To view the output of the sensor, connect the sensor to the device that runs the communication program you are using, and ensure that the sensor has suitable power. The DUALEM sensor is programmed at the factory to provide NMEA output once per second. Upon power up, a sensor with this programming will output start-up information for a few seconds while it performs self-testing, and then commence output of NMEA-compliant sentences.

The output will continue until power is disconnected, or until you send the `[4]` character to the sensor. If you send the `[4]` character, the sensor will change to 4x20 output. Noise received by the sensor through its serial port can cause output to stop; if output unexpectedly stops or changes format, disconnect power, wait several seconds and reconnect power.

If the sensor output is in 4x20 format, you can change it to NMEA-compliant by sending a `$` (ASCII 36) or `%` (ASCII 37) character to the sensor.

4x20 Operation

If you operate with 4x20 output, you can take measurements, set up survey parameters, program the sensor, upload data and access a “hidden” setup menu. 4x20 operation starts from the root menu. If the last 4 lines of your display do not show the root menu, press the [4] key on the device, several times if necessary, until they do. (If you are using a hardwired DUALEM controller, the last line will be 4:SUSPEND).

```
1:SURVEY OPERATION R
2:SURVEY SETUP     O
3:INSTRUMENT SETUP O
4:DATA UPLOAD      T
```

The following sections describe the functions of the root-menu choices, except for `4:DATA UPLOAD` and the hidden menu, which are described in subsequent sections. The key-press sequences assume the use of the DUALEM controller, with which you use the [1] and [2] keys to decrement and increment numerical values (such as line number). If you are using another control device (e.g. a PC), you generally set numerical values by pressing the keys of the number followed by CR/LF (e.g. [ENTER]).

Instrument Setup

Pressing the `[3]` key for `INSTRUMENT SETUP` will enable you to program the way the sensor operates. Each programmable item has prompts and options arranged on 4 lines of output. The items are arranged in an cycle alphabetically by prompt; in general, you press the:
`[1]` key to move to the previous item;
`[2]` key to move to the next item;
`[3]` key to change an option;
`[4]` key to return to the `ROOT` menu.

```
BATTERY: vv.v VOLTS
MEMORY: rrrrr FREE
INTERNAL TEMP:stt°C
1:PREV 2:NEXT 4:BACK
```

Press `[3]` from the `ROOT` menu and the `BATTERY/MEMORY` prompt will appear. `vv.v` represents the battery voltage in use by the sensor. `rrrrr` represents the number of records that currently contain no survey data. `s` represents the sign of the temperature, `tt`, inside the sensor.

```
DATE: yy-mo-dd
TIME: hh:mm:ss
1:PREVIOUS 2:NEXT
3:SET      4:BACK
```

Press `[2]` to move to the `DATE/TIME` prompt. `yy-mo-dd` represents the year, month and day, and `hh:mm:ss` represent the hour, minute and second. To make changes, press `[3]`.

```
SET DATE: yy-mo-dd
    TIME: hh:mm:ss
1:DEC VAL 2:INC VAL
3:CURSOR  4:BACK
```

If you press `[3]`, the `SET DATE/TIME` sub-prompt will appear, with a cursor under the year (`yy`) field. Press `[1]` and/or `[2]` to change the value of the field, or press `[3]` to save its value and move to the next field. When the values in the fields are correct, pressing `[4]` will redisplay the `DATE/TIME` prompt. (If the sensor incorporates a GPS receiver, the time will synchronize automatically to available GPS time, subject to your setting of a UTC offset).

Press `[2]` to move to `DISPLAY CONTROL`. You can ignore this prompt unless you are using a hardwired DUALEM Controller. The `DISPLAY CONTROL` options allow you to set the contrast level of the display, and control the display light. Note that operating with the light on will increase power consumption significantly. If you select

```
DISPLAY CONTROL

1:PREVIOUS 2:NEXT
3:SET      4:BACK
```

[3], the following sub-prompt, with control settings, appears:

```
DISPLAY ADJUSTMENT
1:DECREASE CONTRAST
2:INCREASE CONTRAST
3:LIGHT/OFF  4:BACK
```

Press [1] to decrease the contrast of the display, and [2] to increase it. Press [3] to switch the display light on or off. If you have changed the contrast and want the setting to endure through the next startup, press [3] repeatedly until you see the prompt **STORE CONTRAST**, and press [1]. Press [4] to return to the DISPLAY CONTROL prompt. Press [2] to move to the next item.

```
MEASUREMENT PERIOD
pppppppppp
1:PREVIOUS 2:NEXT
3:CHANGE   4:BACK
```

Pressing [2] displays MEASUREMENT PERIOD, which sets both the time between the recording of successive measurements, and the integration interval for each measurement. The sensor senses continuously the response of the earth to the transmitted field, and integrates the response into values that can be recorded.

If you set the measurement period (pppppppppp) to MANUAL or MANUAL SLOW, measurements will be recorded only when you trigger them. The integration interval is about 1 second for MANUAL, and 4 seconds for MANUAL SLOW.

If you set the measurement period MANUAL/MULTIPLE, each time you trigger acquisition, the sensor will record the number of measurements you specified in REPEATS PER STATION, which is the next prompt in INSTRUMENT SETUP. The integration interval for each measurement is about 1 second.

The other MEASUREMENT PERIOD settings are for automatic triggering. The integration interval for the following settings is the shorter of the measurement period or 1 second. The settings are:
1/50 SECOND for 50 measurements per second. This setting will appear only if the baud rate of the serial port is set to 115000. If this setting is selected and the baud rate is subsequently reduced, the setting will revert to 1/10 SECOND;
1/10 SECOND for 10 measurements per second;
1/8 SECOND for 8 measurements per second;
1/5 SECOND for 5 measurements per second;
1/4 SECOND for 4 measurements per second;
1/2 SECOND for two measurements per second;
1 SECOND for 1 measurement per second;
2 SECONDS SHORT for 1 measurement every 2 seconds;
5 SECONDS SHORT for 1 measurement every 5 seconds, and;
10 SECONDS SHORT for 1 measurement every 10 seconds.

The integration interval is the full measurement period for the settings:
2 SECONDS FULL;
5 SECONDS FULL, and;
10 SECONDS FULL.

The survey targets and techniques indicate which MEASUREMENT PERIOD setting to use. If stations have been established for the precise location of measurements, the MANUAL setting is appropriate. The settings for automatic triggering enable surveys to be conducted quickly and conveniently, although with less positional precision. If you plan to use automatic triggering, the survey target should be broad enough so that its response should be reasonably constant over the distance traversed during the measurement period. In other words, shorter periods should be used with smaller targets and faster survey speeds.

For a typical situation, where buried drums and conductive halos are surveyed at walking speed, the `1 SECOND` setting is generally used. In conditions of low signal (e.g. over coarse, dry soil) or high noise (e.g. near power-lines), surveying slowly, with the integration interval equal to the full measurement period, will improve the quality of the data.

```
REPEATS PER STATION
rr
1:PREVIOUS 2:NEXT
3:CHANGE   4:BACK
```

Press `[2]` to move to `REPEATS PER STATION`. You can ignore this prompt if you will operate with NMEA-format output. `REPEATS PER STATION` sets the number (`rr`) of measurements that the sensor will record before changing the station number. The value can be any integer between 1 and 10. A setting of 1 is typical; a higher setting is used for manually triggered measurements in noisy conditions, or at various heights and/or orientations per station.

```
SENSOR ANGLE
PITCH: spp.p
ROLL:  trr.r
1:PREV 2:NEXT 4:BACK
```

Press `[2]` to move to `SENSOR ANGLE`, which shows the angle of the pitch (sign `s` and degree `pp.p`) and roll (sign `t` and degree `rr.r`) of the sensor. You should adjust the positioning of the sensor as practical to minimize these values. Pitch will be positive if the receivers are higher than the transmitter. Roll will be positive if, when looking at the connector-end of the sensor, the sensor is rotated counterclockwise from its ideal position. The display updates twice per second.

Press `[2]` to move to `START MODE`. The setting (`sssssssssssssssssss`) determines how the sensor will behave the next time it is turned on. The options are `DUALEM DATA` , `NMEA OUTPUT`, `NMEA OUTPUT WITH AUX` and `ROOT MENU`. With the `ROOT MENU` setting, the sensor will output the `ROOT` menu. With any other setting, the sensor goes directly to data output in the indicated format: `DUALEM DATA` has output on 4 lines, `NMEA OUTPUT` provides a NMEA-format sentence with time and measurements, and `NMEA OUTPUT WITH AUX` provides an additional NMEA-format sentence with operational parameters. If, prior to shutting down, one of the automatic settings was selected for `MEASUREMENT PERIOD`, the sensor will automatically start to output data according to that setting, until a `[4]` is pressed or the power is disconnected.

```
START MODE
sssssssssssssssssss
1:PREVIOUS 2:NEXT
3:CHANGE   4:BACK
```

Press `[2]` to move to `STATION FLIP`. You can ignore this prompt if you will operate with NMEA-format output. `STATION FLIP` determines whether the station increment will be reversed on successive survey lines. Settings are `FLIP`, which will reverse the increment, and `NOFLIP`, which will not. `FLIP` is a convenient choice for surveys in which successive lines are traversed in the opposite direction.

```
STATION FLIP
ffffff
1:PREVIOUS 2:NEXT
3:CHANGE   4:BACK
```

Survey Setup

From the `ROOT` menu, pressing the `[2]` key for `SURVEY SETUP` will enable you to reference information for 4x20 output. Thus, you can ignore this section if you will operate with NMEA-format output.

Press `[2]` from the `ROOT` menu of the processor and the `COMMENT` prompt will appear, as it is alphabetically the first in the cycle of survey settings.

`COMMENT` displays the number (`nn`) and contents (`cccccccccccccccc`) of the current comment. Thirty-two comments are stored in the processor; each comment contains up to 16 alphanumeric characters. A comment record can be appended to the records of survey data for purposes such as naming the operator, describing weather conditions, and noting the occurrence of features in the survey area.

```
COMMENT
nn:cccccccccccccccc
1:PREVIOUS 2:NEXT
3:LIST     4:BACK
```

Press `[3]` to display the `COMMENT LIST` prompt. From this prompt, you can press `[1]` to view the previous comment in the list, `[2]` to view the next comment in the list, `[3]` to edit the current comment, or `[4]` to make the displayed comment the current one, and return to the `COMMENT` prompt.

```
COMMENT LIST
nn:cccccccccccccccc
1:PRV CMT 2:NXT CMT
3:EDIT    4:BACK
```

Press `[3]` to display the `COMMENT EDIT` prompt. If you have sent a `T` (or `t`) character to the sensor, you can type in the comment. Otherwise, press `[1]` and `[2]` to select the characters and press `[3]` to move the cursor. Press `[4]` to save the comment and return to `COMMENT LIST`, and `[4]` again to return to `COMMENT` in the series of survey settings.

```
COMMENT EDIT
cccccccccccccccc
1:DEC CHR 2:INC CHR
3:CURSOR  4:BACK
```

Press `[2]` to display the `LINE` prompt, which shows the number (`snnnnn`) of the current survey line. The line number can have any integer or zero value between –30000 and 30000.

```
LINE
snnnnn
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press `[3]` to display the `LINE EDIT` prompt. Use `[1]` and `[2]` to set the number of the line. (`[3]` cancels any change and redisplays the `LINE` prompt.) In this example, the first line of the survey intersects the origin of the grid so its line number equals zero. Press `[4]` to save the value and return to the `LINE` prompt.

```
LINE EDIT
snnnnn
1:DEC VAL 2:INC VAL
3:CANCEL  4:BACK
```

Press `[2]` to display the `LINE INCREMENT` prompt, which shows the increment (`siiii`) that will be added to the number of the current line to give the number for the next line. The increment can have any integer value between –3000 and 3000, but usually it indicates the distance between lines.

```
LINE INCREMENT
siiii
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press `[3]` to display the `LINE INCREMENT EDIT` prompt. Use `[1]` and `[2]` to set the value of the line increment. (`[3]`

```
LINE INCREMENT EDIT
siiii
1:DEC VAL 2:INC VAL
3:CANCEL  4:BACK
```

cancels any change and redisplays the LINE INCREMENT prompt.) Press [4] to save the value and return to the LINE INCREMENT prompt.

Press [2] to display the LINE POSITION prompt, which shows a label (p) to indicate the position of lines on the survey grid relative to the survey origin. The label is appended to the line number. The label is usually N or E, but it can be a different alphanumeric character or blank.

```
LINE POSITION
P
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press [3] to display the LINE POSITION EDIT prompt. Use [1] and [2] to set the value of the position. ([3] cancels any change and redisplays the LINE POSITION prompt. Press [4] to save the position and return to the LINE POSITION prompt.

```
LINE POSITION EDIT
P
1:DEC CHR 2:INC CHR
3:CANCEL  4:BACK
```

Press [2] to display the STATION prompt, which shows the number (snnnnn) of the current station on the current line. The station number can have any integer or zero value between –30000 and 30000.

```
STATION
snnnnn
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press [3] to display the STATION EDIT prompt. Use [1] and [2] to set the station number. ([3] cancels any change and redisplays the STATION prompt.) Press [4] to save the value and return to the STATION prompt.

```
STATION EDIT
snnnnn
1:DEC VAL 2:INC VAL
3:CANCEL  4:BACK
```

Press [2] to display the STATION INCREMENT prompt, which shows the increment (siiii) that is added to the current station number to give the next station number on a survey line. The increment can have any integer value from –3000 to 3000. ffffff shows flip status. The increment usually indicates time for automatic triggering, or distance for manual triggering.

```
STATION INCREMENT
siiii     FS:ffffff
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press [3] to display the STN INCREMENT EDIT prompt. Use [1] and [2] to set the station increment. ([3] cancels any change and redisplays the STATION INCREMENT prompt.) Press [4] to save the value and return to the STATION INCREMENT prompt.

```
STN INCREMENT EDIT
siiii
1:DEC VAL 2:INC VAL
3:CANCEL  4:BACK
```

Press [2] to display the STATION POSITION prompt, which shows a label (p) to indicate the position of stations on the survey grid relative to the origin. The label is appended to the station number. The label is usually N or E, but can be any alphanumeric character or blank.

```
STATION POSITION
P
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press [3] to display the STN POSITION EDIT prompt. Use [1] and [2] to set the station position. ([3] cancels any change and redisplays the STATION POSITION prompt. Press [4] to save the position and return to the

```
STN POSITION EDIT
p
1:DEC CHR 2:INC CHR
3:CANCEL  4:BACK
```

STATION POSITION prompt.

Press [2] to display the SURVEY NAME prompt, which shows a name (ssssssss) of the survey. The name can contain up to 8 alphanumeric characters. An edited name will be written to a header record, to indicate the survey in which data on subsequent records were acquired. The current date is written to the header record as well.

```
SURVEY NAME
ssssssss
1:PREVIOUS 2:NEXT
3:EDIT     4:BACK
```

Press [3] to display the SURVEY NAME EDIT prompt. If you have sent a T (or t) character to the sensor, you can type in the comment. Otherwise, [1] and [2] change characters and [3] moves the cursor. Press [4] to write the name to a header record and to return to the SURVEY NAME prompt. Press [4] to return to the ROOT menu.

```
SURVEY NAME EDIT
ssssssss
1:DEC CHR 2:INC CHR
3:CURSOR  4:BACK
```

DUALEM Data Acquisition

From the ROOT menu, pressing the [1] key for SURVEY OPERATION will enable you to both output measurements in 4x20 format and store the measurements in the memory of the sensor. Thus, you can ignore this section if you will operate with NMEA-format output.

Press [1] to display the SURVEY OPER prompt. The first two lines show the survey name (ssssssss) and date (yy-mm-dd) most recently stored in memory. You press [1] to continue with data acquisition, after which the sensor will behave according to the setting of MEASUREMENT PERIOD. For any non-manual setting of MEASUREMENT PERIOD (i.e. that does not contain the word MANUAL) pressing [1] will initiate the automatic recording of measurements, at the interval specified by the setting. The station (tmmmmmq), measurement number (r), HCP conductivity (ucccc.c), HCP in-phase (viii.i), PRP conductivity (wdddd.d) and PRP in-phase (xjjj.j) will update as recording continues. The array length (a) will be blank if the sensor has one array-pair. If the sensor has more than one array-pair or has an internal GPS, the [3] is enabled to page the display to those measurements or GPS position.

```
SURVEY OPER:ssssssss
STORED DATE:yy-mm-dd
1:ACQUIRE 2:VIEW DAT
3:CMT/LINE/STN 4:BCK
```

```
1:CMT 2:LINE   4:BACK
Lslllllp Stmmmmmq Nr
HaC:ucccc.c I:viii.i
PaC:wcddd.d I:xjjj.j
```

```
1:ACQ 2:LN 3:PG 4:BK
```

A record containing the current comment may be inserted into the ongoing measurement records by pressing [1]; the comment will be displayed momentarily. Pressing [2] increments the current line number (and flips the station increment if the STATION FLIP is FLIP). Pressing [4] stops the automatic recording, and restores the SURVEY OPER prompt.

With a manual setting of MEASUREMENT PERIOD, pressing [1] will a trigger measurement, which will be displayed along with a new set of prompts on the top line of the display. The fields on the second through fourth lines are the same as those documented previously for automatic settings. Pressing [1] again will trigger another measurement. Pressing [2] will repeat the measurement,

```
1:ACQ 2:REPT   4:BACK
Lslllllp Stmmmmmq Nr
HaC:scccc.c I:tddd.d
PaC:ueeee.e I:vfff.f
```

```
1:ACQ 2:RP 3:PG 4:BK
```

i.e. record a second set of values for the same station and measurement number. If enabled, [3] will page the display as with automatic measurement. Pressing [4] will return you to the SURVEY OPER display.

For the MANUAL or MANUAL SLOW setting of MEASUREMENT PERIOD, a single measurement will be taken; for the MANUAL/MULTIPLE setting, the sensor will take the number of measurements specified with REPEATS PER STATION.

To view the response of the instrument without recording data, or to review previously recorded data, press [2] from the SURVEY OPER prompt. The instrument will display its response on lines 3 and 4 of the display, in the same format as a recorded measurement. Pressing [2] will generate another non-recorded response. If there is more than one array-pair, [3] will page the display as described for recorded measurements. Pressing [1] will display previously recorded data, starting with the most recent; data will be displayed according to record type (e.g. measurement, GPS, status, comment, header). After the oldest record has been displayed, pressing [1] will again will cycle the display back to the most recent record. Pressing [4] will return you to the SURVEY OPER display.

```
1:PRV 2:VU 3:PG 4:BK
>>> NOT RECORDED <<<
HaC:scccc.c I:tddd.d
PaC:ueeee.e I:vfff.f
```

From the SURVEY OPER prompt, press [3] and the CMT/LINE/STN prompt will appear. The prompt shows the current comment (cccccccccccccccc),line number (sllll), position (p), and increment (uiii), and station number (tmmmmm), position (q), and increment (vjjjj).

```
CMT:cccccccccccccccc
LINE:slllllp   uiiii
STN: tmmmmmq   vjjjj
1:CMT 2:LN 3:ST 4:BK
```

Subsequently, [1] displays the previous comment in the comment list, [2] displays the next comment in the list, [3] restores the 1:ACQ prompts without recording the comment, and [4] restores the prompts and records the comment.

```
Lslllllp Stmmmmmq Nr
nn:cccccccccccccccc
1:PRV CMT 2:NXT CMT
3:CANCEL  4:BACK
```

Pressing [2] from the CMT/LINE/STN prompt allows you to change the current line number. [2] changes the line number by the line increment. This is done after completing a line and before starting the next line; it can be pressed several times if several survey lines are to be skipped. (If the station flip is set to FLIP, the station increment will be reversed for the next line that is surveyed, regardless of how many line numbers may be skipped.)

```
LINE:slllllp  riiiii
STN: tnnnnnq  ujjjjj
1:PRV LIN  2:NXT LIN
3:CANCEL  4:BACK
```

Pressing [3] changes the station number by the station increment, in case stations are to be skipped. Press [1] to cancel the line/station adjustment if, for example, you have advanced the line or station number beyond the value you want. (If these numbers are incorrect, you can edit them through ROOT menu item 2:SURVEY SETUP.) Press [4] to store the adjustments. Pressing either [1] or [4] will restore the SURVEY OPER prompt.

Memory and Data Structure

If you operate with 4x20 output, measurements will be stored in the memory of the sensor, which may require periodic management.

The memory capacity of the sensor provides space for about 65,000 records of measurements. Sensors are shipped from DUALEM with this memory essentially clear for the acquisition of survey data.

After 4x20 operation, the contents of the memory should be transferred promptly to a PC, and the memory cleared for the acquisition of new data. Following this practice virtually ensures that there will always be ample space in memory for new data, reviewing data in memory will be faster and less prone to error, and the potential for the loss of survey data will be minimized.

Records are added sequentially to the memory. When the memory is full, the sensor will prompt for authorization to over-write the oldest records in memory unless the sensor is set for NMEA-format operation, in which case it will over-write automatically as needed.

NMEA-format Operation

The sensor outputs NMEA-format sentences at the interval set with `MEASUREMENT PERIOD`. If you have a manual setting, each time you send the sensor a `$` or `%` character it will respond with one measurement, even if the setting is `MANUAL/MULTIPLE` with several repeats per station. If you have an automatic setting, the sensor will output sentences in NMEA-format at the specified rate, and according to the setting of `START MODE`.

The sensor will send the following sentence in response to the `$` character for each of its array-pairs:

```
$PDLMl,hhmmss.sss,wdddd.d,xeee.ee,ypppp.p,zqqq.qq*cc
```

where `l` is the nominal array-length in m, `hhmmss.sss` is the hour-minute-second time of the measurement (`hhmmss` if the ms output has been turned off with the hidden menu), `w`, `x`, `y` and `z` are the signs (i.e. + or -) of the measurement components, `dddd.d` is the HCP conductivity in mS/m, `eee.ee` is the HCP inphase in ppt, `pppp.p` is the PRP conductivity in mS/m, `qqq.qq` is the PRP inphase in ppt and `cc` is the hexadecimal checksum of values in the output. Note that the fields of the measurement components may be shorter than those shown here, as the output does not incorporate leading blanks (except one place ahead of the decimal point).

The sensor will send the previous sentence(s), plus the following sentence, in response to the `%` character:

```
$PDLMA,wvv.vv,xtt.t,ypp.p,zrr.r*cc
```

where `w`, `x`, `y` and `z` are the signs (i.e. + or -) of the operational parameters, `vv.vv` is the voltage applied to the sensor, `tt.t` is the internal temperature of the sensor in degrees-C, `pp.p` is the pitch of the sensor in degrees, `rr.r` is the roll of the sensor in degrees and `cc` is the hexadecimal checksum of values in the output. Note that the fields of the parameters may be shorter than those shown here, as positive quantities may have no sign and output does not incorporate leading blanks.

If output from the accelerometer and magnetometer are enabled, the sensor will also send the following sentence:

`$PDLMB,ugggg,vhhhh,wiiii,xllll,ymmmm,znnnn,sss.s*cc`

where `u`, `v`, `w`, `x`, `y` and `z` are the signs (i.e. + or -) of the operational parameters, `gggg`, `hhhh` and `iiii` are, respectively, the x-, y- and z-components of acceleration in Gal, `llll`, `mmmm` and `nnnn` are, respectively, the x-, y- and z-components of the ambient magnetic field in μT-times-10; components are relative to the sensor. `sss.ss` is another internal temperature of the sensor in ^{o}C and `cc` is the hexadecimal checksum of values in the output. Note that the fields of the parameters may be shorter than those shown here, as output does not incorporate leading blanks.

If the sensor has a built-in GPS receiver that is enabled, it will also send the following sentence once per second, or with each manual measurement:

```
$GPGGA,hhmmss,llnn.nnnn,d,ooopp.pppp,e,q,tt,uu.u,aaaaa.a,M,gggg.g
,M,ww,rrrr*cc
```

where `hhmmss` is the hour-minute-second of coordinated universal time (UTC), `ll` is the degrees of latitude, `nn.nnnn` is the minutes of latitude, `d` is the hemisphere (i.e. N or S) of latitude, `ooo` is the degrees of longitude, `pp.pppp` is the minutes of longitude, `e` is the hemisphere (i.e. E or W) of longitude, `q` is the quality of the GPS position, `tt` is the number of the satellites contributing to the GPS position, `uu.u` is the horizontal dilution of precision, `aaaaa.a` is the altitude above mean-sea-level, `M` is the units (metres) of altitude, `gggg.g` is the geoidal height, `M` is the units (metres) of height, `ww` is the number seconds since the last differential-GPS update, `rrrr` is the identification of the differential-GPS reference, and `cc` is the hexadecimal checksum of values in the GPGGA sentence. Note that the fields of the parameters may be shorter than those shown here, as the output does not incorporate all leading blanks.

If you send the sensor any character other than `$` or `%`, it will revert to 4x20 output. If the character is a `1`, `2`, `3` or `4`, the sensor will execute the relevant menu function.

StarPal HGIS software supports communication with DUALEM sensors and tabulation of the NMEA-format output. If you are using other software, you may need to set the communication parameters as shown in the Terminal Operation section.

Surveying

After arrival at the survey site, find a location away from any highly conductive objects or obvious sources of electrical interference. If the sensor has been off for at least 5 minutes or so, on startup it automatically performs internal tests to identify its current state, and strong external signals can interfere with this process.

Large and localized changes between measurements may indicate the presence of geometrically confined conductors, such as buried drums, trenches, pipes, etc. Note that the PRP geometry is asymmetrical over confined conductors, and consistent response requires consistent orientation of the sensor. For example, where surveying follows a serpentine path, the sensor should be readjusted as necessary to keep its geographical orientation constant.

The coils of the sensor form the HCP and PRP geometries when the DUALEM label on the end-cap without the connector, is upright and level. Note also that you can orient the coils in the vertical coplanar and null geometries by rotating the sensor so that the label is vertical. Accordingly, some care should be taken during surveying to maintain the sensor in the planned orientation.

Data Quality

Data of good quality are free of noticeable offset, drift and environmental noise. Offset is the value measured by a sensor where no conductive material is present. Drift is the change in offset with temperature or time. Environmental noise may arise from electrical activity in the atmosphere, or nearby electrical-power facilities.

When initially shipped, offset and drift for DUALEM conductivity measurements are about 1 mS/m over typical operating ranges, and data quality should not deteriorate with normal use of the sensor.

Drift may be reduced if differential heating and cooling is minimized. Helpful procedures include allowing the sensor 30 minutes to reach ambient temperature before taking measurements. Applying power to the sensor during this time can be beneficial, especially where ambient temperatures are low. Where convenient, mounting the sensor beneath or within an opaque light-colored cover can reduce heating due to sunlight.

Where temperatures fluctuate greatly, drift can be monitored and corrected by periodically recording a set of measurements at a reference location.

DUALEM instruments operate in a narrow band around 9 kHz, and are thus are relatively immune to environmental noise that is broadband (e.g. atmospheric) or offset in frequency (e.g. 50/60 Hz and harmonics). Furthermore, environmental noise typically has some directionality, and may be reduced by orientating the DUALEM in a source-specific way. For example, orienting the instrument north-south may reduce atmospheric noise emanating from equatorial regions.

Data Processing

You can transfer DUALEM-format data stored in the memory of the sensor to a PC using the *duupload5.exe* program that can be downloaded from www.dualem.com, or by a standard PC terminal program. DUALEM software will format the data for export to widely used software for editing, imaging, and interpretation. DUALEM software can be installed on standard PCs that run under Windows 95 or subsequent operating systems.

Transfer of Data

Duupload5.exe creates a PC text file from the data that follow each header record in the processor memory. The file *default.** (where * indicates the file format) is created from any data that precede the first header record. Otherwise, the file name contains the survey name stored in the header record.

If two or more header records have the same survey name, the hour-minute-second of the later header record is appended to the survey name to form the file name. If the exact file name already exists in the PC directory, *duupload5.exe* erases it.

To use *duupload5.exe*, ensure that it is available for execution from a folder to which the program can write files. (Some versions of Windows will not write files to the C:\ root directory). Connect the data cable to the connector on the boom and to the serial port on the PC. If your PC has no serial port, you can use a suitable USB-serial interface cable.

If you run *duupload5.exe* by double-clicking (etc.) from Windows, it will execute using the default values of format, port and speed. The default port is COM1. The default speed is 57600 baud although the program will shift automatically to other speeds, if feasible, during data transfer. The default format is simple xyz; the fixed-width fields of its records, with their formats, are from left to right:
Station number – I6
Station position – A2
Line number – I6
Line position – A2
Shorter array horizontal co-planar conductivity (mS/m) – F9.2
Shorter array horizontal co-planar in-phase (ppt) – F9.2
Shorter array perpendicular conductivity (mS/m) – F9.2
Shorter array perpendicular in-phase (ppt) – F9.2
Longer array horizontal co-planar conductivity (mS/m) – F9.2
Longer array horizontal co-planar in-phase (ppt) – F9.2
Longer array perpendicular conductivity (mS/m) – F9.2
Longer array perpendicular in-phase (ppt) – F9.2
Measurement number – I2
Hour – I2
Minute – I2
Second – I2
Battery voltage (V) – F7.3
Internal temperature (° K) – F7.1
Comment number – I5
Pitch (°) – F4.2
Roll (°) – F4.2
GPS Time (ms) – I12
Latitude (degrees.minutes*10000) – F12.6
Longitude (degrees.minutes*10000) – F12.6
Elevation (m) – F7.1
GPS Mode (0=poor, 1=good, 2=differential) – I2

The last 5 fields of the record will contain zeros if there was no fix from an internal GPS at the time of the measurement.

If you run *duupload5.exe* from a Windows command prompt, you can select options for serial port, upload speed and output format. (If you enter `duupload5 ?` at the command prompt, you will get a list of the options.) The general form of the command is:

```
duupload5 [serial port] [upload speed] [output format] [height]
```

where the option(s) for:

`[serial port]` are com1, etc., according to the port connected to the data cable;
`[upload speed]` are 9600, 19200, 38400, 57600 or 115200, according to the baud rate to try first;
`[output format]` are x for simple xyz (**.xyz*), g for a Geosoft-style documented xyz (**.xyz*), d for DAT31-style (**.g31*), p for EM amplitudes in ppm (**.ppm*), l for log (**.log*) or r for raw (**.raw*). If you specify a format other than raw, *duupload5.exe* will create a file of raw data in addition to the file in the format you chose. The file name for the RAW file has the following form: Xhhmmss-MMDDYYYY.RAW, where hhmmss is hours- minutes-seconds of the start of data unloading, and MMDDYYYY are month-day-year of data unloading. It is best practice to keep an archive of raw-format files, as each such file represents a complete image of instrument memory and can be used to troubleshoot issues that may later be observed in processed data;
`[height]` is the nominal height of measurement above the surface. This parameter is used only if the option for output format is p for ppm.

The options for serial port, upload speed and output format can be entered in any order but height, if required, is always the final item in a command line. For example, if you entered:

```
duupload5 com2 115200 g
```

at the command prompt for the directory that contains *duupload5.exe*, you would transfer data through serial port COM2 at 115200 baud into a documented file.

Data will scroll up the window during transfer. When the transfer is complete, you will be prompted to choose whether to erase the survey data in the instrument. After you make your choice, the transfer process is over and transcription of the data that have been uploaded begins. You will always be prompted to enter either the sensor height in metres followed by <Enter> or to enter the slash symbol / followed by <Enter>. You must enter either a numerical height or a slash (/) symbol, followed by pressing the <Enter> key, in response to this prompt: If you do not, data transcription to your desired output format will not take place.

The g-style xyz file is similar to the simple xyz file, but adds of 3 lines of documentation at the top of the file and places comment lines within the file as they occur. The top lines document the (i) filename, (ii) DUALEM sensor-type and (iii) column headings. The first character of the top lines and any comment line is a \ (ASCII 92).

The d-, l-, p- and r-style files are not in general use. For the d-style file, HCP measurements are labeled with the alternate description of Vertical Dipole, and PRP measurements are labeled with the approximate description of Horizontal Dipole.

Raw data may be transferred to a PC using either *duupload5.exe* or a standard PC terminal program (e.g. HyperTerminal, supplied with pre-Vista versions of Windows). The first raw-data record uploaded will be a specific type of comment record, containing the instrument model, the serial number and the version of the instrument software. The general format of the comment record is:

C$hhmmss:cccccccccccccccc

where hhmmss is the time at which the comment was recorded, and cccccccccccccccc is the comment.

If you edited `SURVEY NAME` before acquiring data, the next record will be a header, with the following format:

H$hhmmss:nnnnnnnn:yyoodd:ttt

where hhmmss is the hour, minute and second at which the header was recorded, nnnnnnnn is the name of the survey, yyoodd is the year, month and day of recording, and ttt is the model of DUALEM instrument used to record the data.

The format of the data-record is:

D$hhmmss.sss:tllllp:uoooooqn:wcccccxiiiiiydddddzjjjjj:vvvvv:kkkkk:apppbrrr

where hhmmss.sss is the hour, minute and second of data recording if milliseconds are enabled; if not, the time format will be hhmmss. t is the sign of the line number, lllll is the line number, p is position of the line, u is the sign of the station number, ooooo is the station number, q is position of the station, n is number of the measurement at the station, w is the sign of the HCP conductivity, ccccc is the HCP conductivity in mS/m-times-10, x is the sign of the HCP in-phase, iiiii is the HCP in-phase in ppt-times-100, y is the sign of the PRP conductivity, ddddd is the PRP conductivity in mS/m-times-10, z is the sign of the PRP in-phase, jjjjj is the PRP in-phase in ppt-times-100, vvvvv is the applied voltage in mV, kkkkk is the internal temperature of the instrument in K-times-100, a is the sign of the pitch and b is sign of the roll. If the angle of pitch or roll is less than 20 degrees, ppp is the pitch in degrees-times-10, and rrr is roll in degrees-times-10; if pitch or roll is greater than 20 degrees, it is reported in degrees (no tenths), and 300 is added to its absolute value to distinguish the value from one which includes tenths. As examples, a roll of -21 degrees would be reported as -321, and a roll of +177 degrees would be reported as +477.

If the accelerometer and magnetometer are enabled, stored output will be uploaded in the following format:

A$ugggggvhhhhhwiiiii:xllllllymmmmmznnnnn:sssss where u, v, w, x, y and z are the signs (i.e. + or -) of the operational parameters, ggggg, hhhhh and iiiii are, respectively, the x-, y- and z-components of acceleration in gal-times-10, lllll, mmmmm and nnnnn are, respectively, the x-, y- and z-components of the ambient magnetic field in µT-times-100; components are relative to the sensor. sssss is another internal temperature of the sensor in K-times-100.

The extension raw-data record contains data from the longer array(s) of the sensor. The format of the extension record is:

```
X$hhmmssrbbbbbtiiiiiucccccvjjjjjwdddddxfffffyeeeeezggggg
```

where `hhmmss` is the time of data recording; for the longer array, r is the sign of the HCP conductivity, `bbbbb` is the HCP conductivity in mS/m-times-10, t is the sign of the HCP in-phase, `iiiii` is the HCP in-phase in ppt-times-100, u is the sign of the PRP conductivity, `ccccc` is the PRP conductivity in mS/m-times-10, v is the sign of the PRP in-phase and `jjjjj` is the PRP in-phase in ppt-times-100.

If the sensor has a third pair of receivers, for the longest array w is the sign of the HCP conductivity, `ddddd` is the HCP conductivity in mS/m-times-10, x is the sign of the HCP in-phase, `fffff` is the HCP in-phase in ppt-times-100, y is the sign of the PRP conductivity, `eeeee` is the PRP conductivity in mS/m-times-10, z is the sign of the PRP in-phase, `ggggg` is the PRP in-phase in ppt-times-100.

The raw-data record for GPS-fixes is the NMEA-standard GPGGA sentence with the prefix `G`. Such records will be present if the sensor has a built-in GPS receiver that was enabled during surveying.

You can also transfer data in raw format using a suitable terminal program, such as HyperTerminal, instead of *duupload5.exe*. To transfer data in this way, start the terminal program, display the root menu, and press `[4]` from the root menu for DATA UPLOAD. If you find the terminal program has problems with the data transfer, run it again and press the `[s]` key in response to the prompt "`PRESS ANY KEY TO BEGIN TRANSFER`" to slow down the data rate. If you still have problems, press the `[S]` key instead.

The files of ASCII characters in fields of fixed length created by *duupload.exe* can be imported easily into spreadsheet programs such as Excel and Lotus. These programs provide convenient ways to edit position and measurement data in tabular form, sort records, and to generate profiles of survey lines.

Hidden Menu

There are several instrument settings that are rarely changed, of which some affect the operation of the sensor profoundly. For these reasons, the settings are gathered in a "hidden" menu so they will be unobtrusive and difficult to change accidentally.

From the root menu, press `[3]` for `INSTRUMENT SETUP` to display the `BATTERY/MEMORY` prompt. Press `[5]` 5 times. The display will show `ENTER CODE 1423:` to request the code `1423`. After you enter this code, the following menu will be available:

```
1:ZERO OUTPUT
2:SHOW MS ON/OFF
3:SET USER OFFSETS
4:BACK
5:ACC/MAG ON/OFF
6:SET BAUD RATE
```

If you press [`1`], the sensor will fix the conductivity and inphase values of the most recent measurement as zero-level references until power is disconnected. Thus, these temporary references will be subtracted automatically from subsequent measurements. Disconnecting and reconnecting power will restore the original references.

If you press [`2`], the display will show the unit of time (either milliseconds or seconds) from the clock in the sensor, and you will have the option to change the unit. Time in the specified unit is both stamped on measurement records logged internally and output in NMEA sentences that contain EM data (*e.g.* the $PDLM1 sentence for 1-m arrays). If there is an internal GPS receiver that has a satellite fix, the time stamp will synchronize to it.

If you press [`3`], you will access a menu that allows you to enter zero-level offsets that will be added to future measurements. (The second character in the prompt indicates the nominal array length, *e.g.* HHC is HCP Half-m Conductivity, P1C is PRP 1.1-m Conductivity, etc.) Entering any offset will change the calibration of the sensor, as the offset will remain after power is disconnected.

After you have saved any offset, pressing [`4`] again will return you to the root menu.

If you press [`5`] the display will show the on/off status of output from the internal accelerometer and magnetometer, and you will have the option to change the status. If output is on, data will be both logged internally and incorporated in the $PDLMB sentence.

If you press [`6`] you will access a menu that lets you change the baud rate of the serial port of the sensor to 9600, 38400 or 115200. The change will take effect after power is disconnected and reconnected.

DUALEM-1H Technical Specifications

EM-array geometries:	Horizontal coplanar (HCP) and perpendicular (PRP) (or vertical coplanar and “null” if rotated 90 degrees);
Array properties:	0.5-m HCP, 0.6-m PRP, 1-m HCP and 1.1-m PRP lengths, operating at 9 kHz;
Measured quantities:	HCP conductivity (HC) and PRP conductivity (PC) in mS/m, HCP in-phase (HI) and PRP in-phase (PI) in ppt;
Measurement ranges:	HC/PC: ± 3000 mS/m, HI/PI: ± 300 ppt;
Data rates:	Manual, or continuous at rates between 0.1- and 50-Hz;

Integrated components:	3D accelerometer/tilt-meters, 3D magnetometer, Bluetooth transceiver, clock, digital signal processor, indicator LEDs, RS-232 port, thermometers;
Data capacity:	65,000 records of survey- and ancillary-data;
Output format:	Proprietary or NMEA-compliant ASCII text;
Power requirement:	3 W from 12 (± 3) V DC through AC-Micro connector;
Weights:	5 kg operating, 11 kg shipping;
Sensor dimensions:	0.089-m diameter, 1.59-m length;
Shipping dimensions:	Tube: 1.7 x 0.15 x 0.21 m, and Box: 0.33 x 0.18 x 0.13 m;
Ancillary items:	Shipping container, controller with GPS, data/power cable, harness, software and documentation.

Warranty

Dualem Inc. will repair any defects in the materials or workmanship of new equipment encountered during reasonable and normal use of said sensor at its own expense for a period of 6 months from the date of shipment of the sensor by Dualem to Dualem's customer. Unreasonable or abnormal uses which will invalidate this warranty include but are not limited to the following: physical abuse; exposure of the sensor to power voltage greater than 15 VDC and/or high radiation levels and/or corrosive environments and/or extreme temperatures and/or excessive vibration and/or excessive mechanical stress; immersion of any part of the sensor in water or other liquids; airborne, marine or submarine applications; disassembly, x-raying or other direct or indirect access to the electronics and sensor elements and mechanisms by unauthorised personnel.

Dualem will examine and make repairs to a DUALEM sensor that are necessary during the warranty period, or requested following this period, if said sensor is returned, free of claims or charges, to Dualem's repair facility. Dualem recommends that the customer contact Dualem through inbox@dualem.com or by telephone number 1 905 876 0201 to discuss any apparent defect prior to any planned return of the instrument.

Following a repair during the warranty period, Dualem will provide return shipment of the sensor; the customer is responsible for charges related to insurance, customs, etc. After the warranty period, the customer is responsible for all charges related to examination, repair, shipment, etc.

The foregoing is the sole and complete warranty of Dualem Inc. Dualem Inc. neither expresses nor implies any other warranty nor is subject to any liability regarding the materials of and/or performance of and/or suitability for any purpose of and/or the usability of any data from any sensor with which Dualem Inc. has any association.