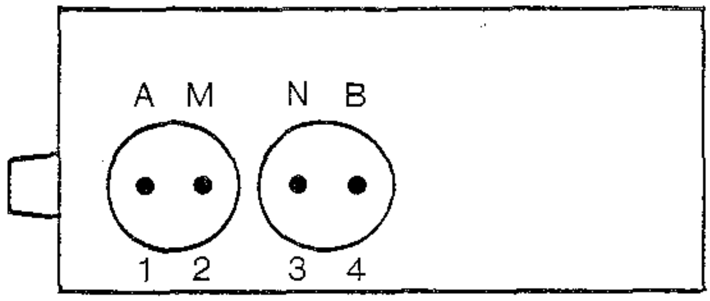
APPENDIX A

CURRENT AND POTENTIAL TERMINALS

A-1 Pin connections

The Current and Potential pin connections are shown below, figure A-1. It can be seen that the "Mobile Probes" and "Remote Probes" connectors each consist of a current and potential pin. Pins A and B are current output pins whilst M and N are potential input pins. The leads of the PA3 Four probe kit are marked to correspond with the sequences AMNB and 1234. The sequence AMNB is the more conventional identifier.



A or 1 Current Output
M or 2 Potential Input
N or 3 Potential Input
B or 4 Current Output

Figure A-1. Current and Potential pin connections.

The current pins are galvanically isolated from the potential pins and the internal circuitry. The potential pins are connected to an internal amplifier, but are not galvanically isolated from the internal circuitry, including system ground. Therefore, you should ensure that any equipment connected to the analogue output is insulated from the earth's surface or surface vegetation. If this precaution is not taken then serious reading errors can occur.

WARNING

Always isolate any equipment connected to the analogue output from ground otherwise you may experience severe measurement errors.

A positive reading will be obtained when the potential difference between A and M is smaller than that between A and N, ie probes connected to AMNB are laid out in a line in the sequence AMNB. If the M and N probes are transposed, then a negative reading will occur.

APPENDIX B

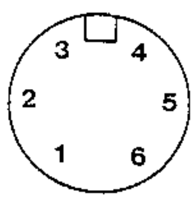
CHARGER, ANALOGUE, RANGE CONNECTIONS

B-1 Introduction

The six way plug labelled as (4) in figure 2-1 of section 2 acts as a connector for Charger Input, Analogue Output and Range Status Output. The battery charger plugs into this connector and allows the batteries to be recharged without undoing the case. An analogue output signal is provided for data logging or chart-recorders. Range status information is provided via two logic bits for data loggers.

B-2 Pin Connections

The pin connections of the six-way plug are shown in figure B-1. Pins 1 and 2 are used for the charger input (only use the constant current charger supplied with the RM4). Pins 3 and 4 are used for the analogue output (see section 4-6 for further details). Pins 1, 2, 5 and 6 are used for the range status output (see below for further details).



1 Charger +ve / Range status reference
2 Charger -ve / Range status ground
3 Analogue output - signal
4 Analogue output - ground
5 Range Status - Bit 1
6 Range Status - Bit 2

Figure B-1. Pin connections for charger input, analogue and range status output.

B-3 Range Status Outputs

Range status information is provided via two logic bits for data loggers. The logic bits can also indicate if contact resistance is greater than the compliance of the RM4 - in other words if a current probe is out of the ground. They may therefore be used to detect when the mobile frame of Twin array is re-inserted into the ground, and hence trigger an external data logger to automatically take a reading. A truth table of the status output bits is shown below :

	Bit 1 (pin 5)	Bit 2 (pin 6)	
2000 ohm range	0	0	
200.0 ohm range	0	1	0 = Logic 0
20.00 ohm range	1	0	1 = Logic 1
Current probe out of the ground	1	1	

Table B-1. Logic Table for Range Status Bits.

This information can be used, in conjunction with the analogue output, to provide automatic logging of the data. The advantage of logging data with the range status output bits, as opposed to using the analogue output alone (see section 4-6), is that a record can also made of the range in use and a reliable indicator of when a current probe is out of the ground is obtained. The voltage levels of the logic outputs are :

Logic 1 = approx. -0.4V with respect to Charger +ve (pin 1)
Logic 0 = approx. -4.4V with respect to Charger +ve (pin 1)

(Charger +ve is approx. -0.3V wrt battery +ve)

Interface circuitry should have a high input impedance and is best configured using analogue comparators or operational amplifiers. A means of interfacing to 5V logic levels is shown in figure B-2.

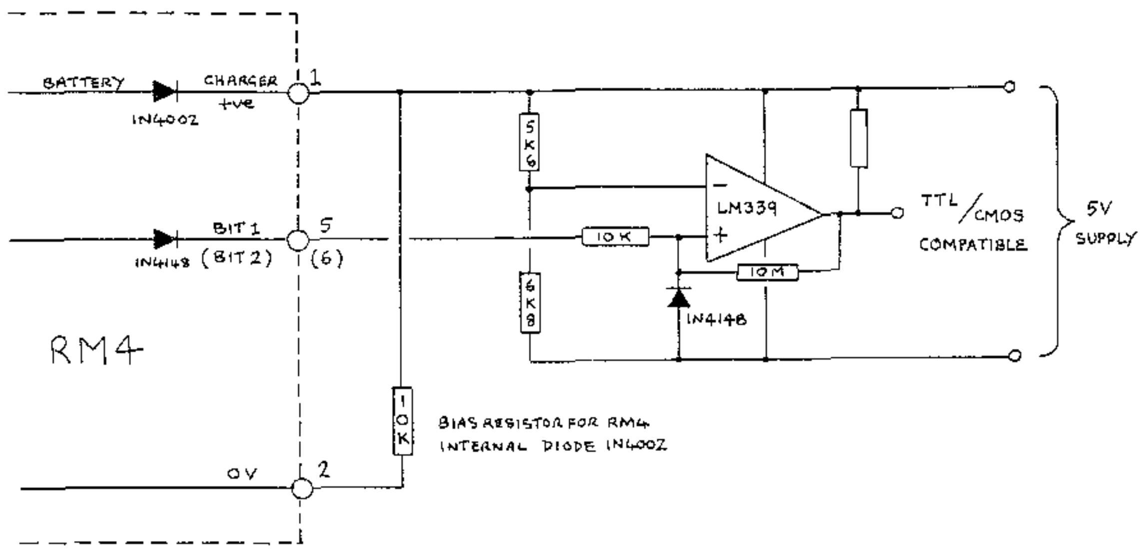


Figure B-2. Suggested Range Status interface circuitry.

Any circuitry attached to the range status and analogue output connector **MUST** be isolated from ground for correct measurements. If it is not properly isolated leakage currents may flow through your body, causing severe measurement errors.

WARNING

Always isolate any equipment connected to the range status and analogue output from ground otherwise you may experience severe measurement errors.

APPENDIX C

MAKING YOUR OWN TWIN ARRAY

C-1 Introduction

This Appendix provides guidelines for making your own 0.5m Twin array system. The design may be modified to suit your own purposes.

C-2 Mobile Frame

An outline drawing of the mobile frame, is shown in figure C-1. This shows typical dimensions, materials and placement of handle grips which will give a lightweight, yet robust frame, that is comfortable to use. The following points should be closely observed.

1 The steel frame and probes should be mounted on an insulating cross beam made from a hardwood such as mahogany or keruing. The beam cross section should be 50mm by 50mm to provide good strength. It should be finished in the central section by linseed oil to provide protection against water. The outer sections can optionally be finished with several coats of paint : first aluminium wood paint, second primer/sealer, followed by at least two coats of paint suitable for outdoor use and rough handling.

2 The probes may conveniently be made from 250mm lengths of 12mm threaded steel rod, preferably stainless steel. The end to be inserted into the ground should be filed into a non-sharp point.

3 All cabling should be firmly clamped to the frame to minimise variations in capacitive coupling. It is suggested that pvc sheathed, 6A, twin-core mains cable is used for the length of cable running from the RM4 connector to the wooden beam.

4 Electrical connection to ordinary steel probes may be made by first filing the tops of the probes, then using a blow lamp at a low setting, tin the tops with a resin-cored solder suitable for electrical work. Next, tin the cable which may then be soldered to the probe tops. If you use stainless steel probes then you should drill and tap a hole in the top to take an M4 bolt. Solder the cable to solder tags which are then attached to the top of the probes by M4 bolts.

5 When fixing the probes to the wooden beam it is **IMPERATIVE** that additional electrical insulation is used between the probes and the wood. It is not sufficient to rely on the insulating properties of the wood. It is suggested that short lengths of plastic tube are set into the wood and that nylon washers separate the nuts, which are used to fasten the probes to the wood, from the wood surface. Use locking compound with the nuts to prevent them shaking loose.

6 Once the probes are mounted on the beam, any exposed electrical connections should be encapsulated in a resin or plastic compound, (non- corrosive), such as "Plastic Padding" used for car body repairs, and finished with a rubberised car-body underseal to exclude moisture. The bolts on the under side of the beam should be similarily sealed.

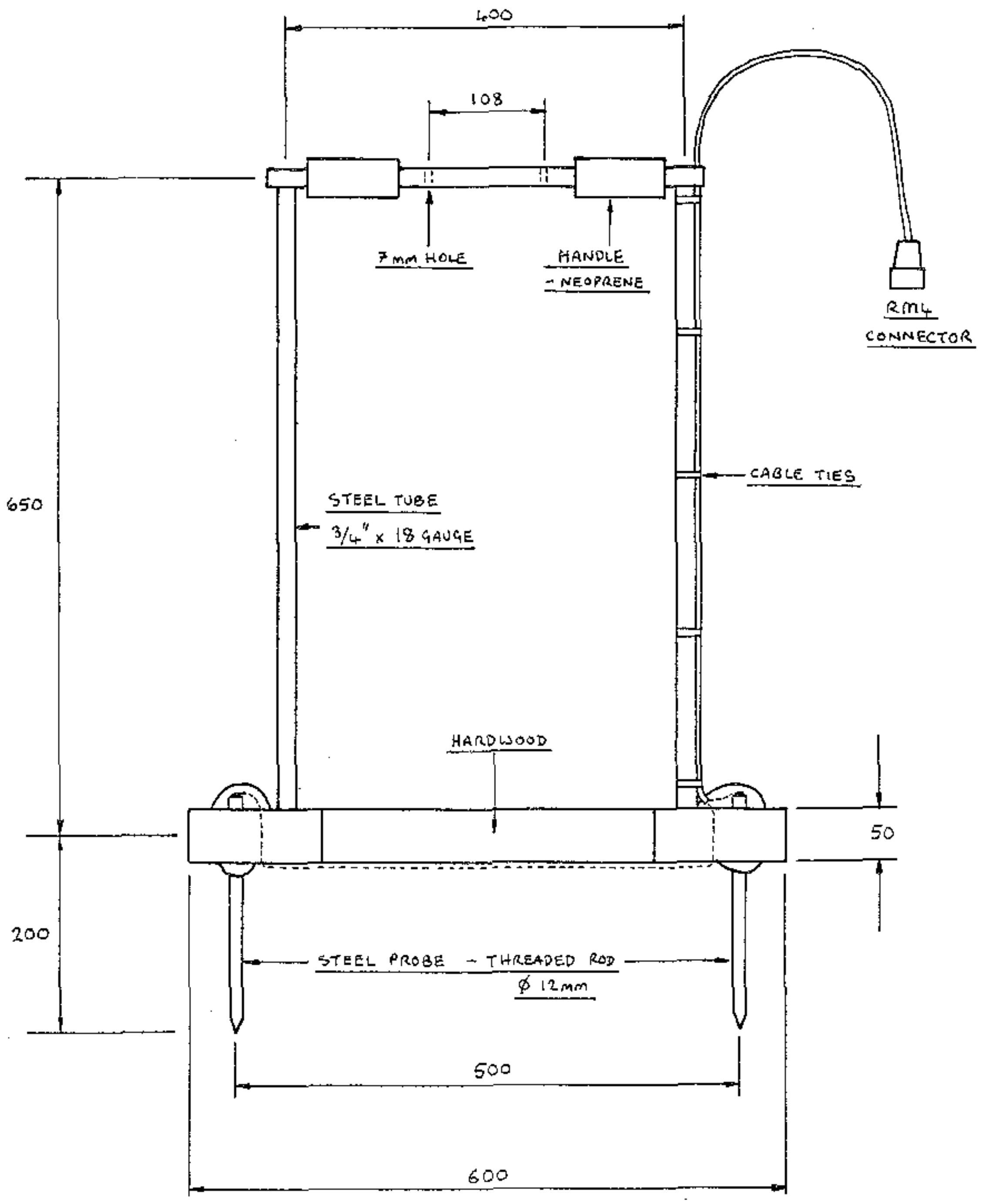


Figure C-1. Mobile Frame construction.

C-3 Remote Probes

For general purpose use remote probes should be of similar construction and dimensions to those on the mobile frame, although of course each probe should be independant of one another and not joined by a wooden beam. Typically these will consist of an "L" shape, 20 cm vertical length, 10 cm horizontal length, with the far end of the 20 cm length filed into a non-sharp point. The 10 cm length should ideally have a hole drilled in the end to take a 4mm plug. This will connect via a 2m lead to the remote probe cable drum - see below. Alternatively you can use "Bulldog" or "Crocodile" clips to connect to the probes. Unless you use stainless steel you may find it sometimes difficult to ensure a good electrical connection due in the presence of rust deposits on the exposed metal.

C-4 Connecting Cable

Suitable cable for connecting the remote probes to the mobile frame is pvc sheathed, 6A twin-core mains cable. The length should not exceed 50m since the resulting increase in cable capacitance will lead to excessive offsets in the background resistance, long setting times and reading variation with contact resistance. The cable should be stored on a cable-drum and it is most convenient to connect the cable to a pair of 4mm sockets mounted on the drum itself. Two 2m leads can then connect from the drum to the remote probes.

C-5 Twin Array Wiring

The connection of the probes to the RM4 resistance meter are shown in figure C-2. Note that it does not matter which of the mobile frame probes is connected as current or potential probe so long as both are connected to the same plug at the RM4 and the same goes for the remote probe.

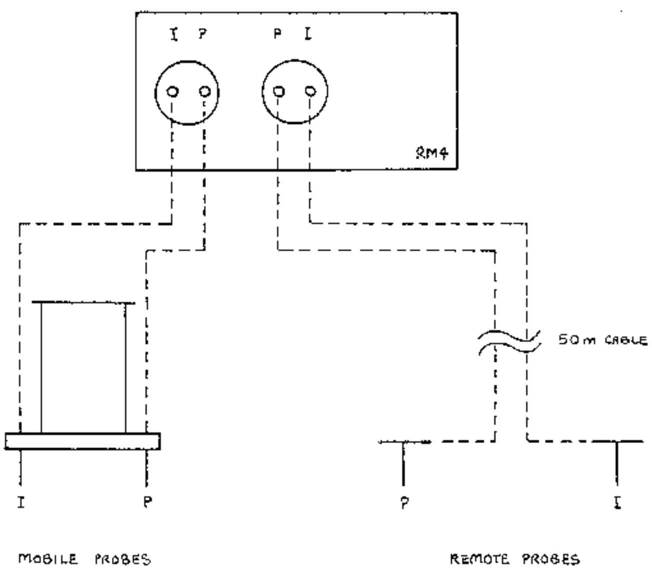


Figure C-2. Twin Array wiring.

APPENDIX F

SURVEY AIDS

F-1 Grid Diagonal Dimensions

Table F-1 shows the diagonal dimensions of various grid sizes. These may be used to define a right angle when layout out a grid.

Survey Grid Dimensions	Diagonal
10 x 10 m	14.14 m
20 x 20 m	28.28 m
30 x 30 m	42.43 m
10 x 20 m	22.36 m
10 x 30 m	31.62 m
20 x 30 m	36.06 m

Table 5-1. Diagonal dimensions of various grid sizes.

F-2 Survey Guide Line Colour Coding

The survey guide lines (no longer available from Geoscan Research) are of a length suitable for surveying on 20m grids and are graduated for taking readings at 1m and 0.5m intervals. The lines are intended for use only as guide lines for surveying, and not for accurate marking out of survey grids, since the nylon lines will stretch slightly. The colour coding used is as follows :

The central perpendicular line, along which traverses are made, is terminated at each end with a black band.

The two parallel lines, which determine the position of the central perpendiculare line, are terminated at each end with blue bands.

The centre of each line is marked by a black band, and indicates when 20 readings have been taken at 0.5m intervals.

Marker points for surveying at a 1m reading interval are yellow.

Marker points for surveying at a 0.5m reading interval are red.

F-3 Survey Sheets

Copies of the survey sheets opposite may be useful for recording essential details of the site, for example layout of the grid pattern, weather conditions, geology etc. This will be of particular use when it comes to presenting and interpreting the survey at a later date.

GR Geoscan Research

GEOPHYSICAL SURVEY

SITE	SHEET NUMBER
	DATE
	MAP REF.
SOIL	SURVEY TYPE
SUBSOIL	
GROUND COVER	
WEATHER	INSTRUMENT
SHEET ORIENTATION N / ADJACENT SHEETS	STATION INTERVAL
	UNITS
	SURVEYORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
A																					A
B																					B
C																					C
D																					D
E																					E
F																					F
G																					G
H																					H
I																					I
J																					J
K																					K
L																					L
M																					M
N																					N
O																					O
P																					P
Q																					Q
R																					R
S																					S
T																					T
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	

Geoscan Research

GEOPHYSICAL SURVEY

SITE	SHEET NUMBER
	DATE
	MAP REF.
SOIL	SURVEY TYPE
SUBSOIL	
GROUND COVER	
WEATHER	INSTRUMENT
SHEET ORIENTATION N / ADJACENT SHEETS	STATION INTERVAL
	UNITS
	SURVEYORS

APPENDIX G

SEALED CONNECTORS

G-1 Assembly Instructions

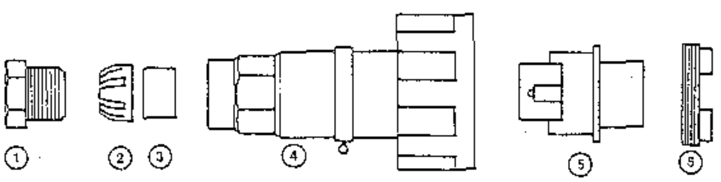
Cable Socket and In-Line Cable Plug

Fig. 1

1. Prepare cable to lengths shown in Fig. 1. When using 2 or 3 way connectors the cable diameter must be between 6 to 8.1mm and 7 to 9mm when using 6 way connectors.
2. With the aid of tool (Fig. 3) remove insert retaining ring(6)(Fig. 2) and withdraw insert from the outer shell. If a different connection configuration is required simply replace or exchange inserts to suit individual requirements.
3. Undo the cable retaining nut(1)and remove cable grip and sealing gland.
4. Feed cable retaining nut, cable grip, sealing gland and connection outer shell over prepared cable and terminate appropriate colour wire onto the corresponding terminal on insert

5. Pull the cable back gently until insert is in the connector housing. Note that the insert has a flat on the mounting flange which aligns with a corresponding flat inside the outer shell. Fit retaining ring(6)over the insert and with the aid of the tool, lock the retaining ring by turning tool in a clockwise direction to torque limits of 0.40Nm min, 2.82Nm max.
6. Push sealing gland, and cable grip into the connection shell and tighten the cable retaining nut to limits of 1.70Nm min, 4.00Nm max.

Cable Socket



1. Cable retaining nut
2. Cable grip
3. Sealing gland — 6 – 8.1mm for 2 and 3 ways, 7 – 9mm for 6 way free cable connectors.
4. Cable socket outer shell
5. Socket insert
6. Insert retaining ring

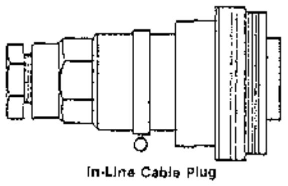
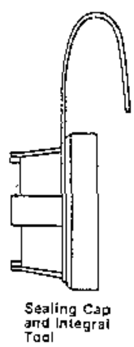


Fig. 2

In-Line Cable Plug



Sealing Cap and Integral Tool

Fig. 3

APPENDIX H

CONVERSION TO RESISTIVITY

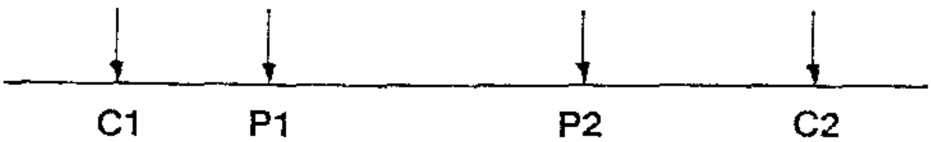
H-1 Introduction

The RM4 displays and logs readings in units of resistance (ohms), not resistivity units (ohm-m). This can be used directly if you are just wishing to locate structures in the ground. However, using resistance as the units means that if you make measurements over the same piece of ground, with different probe configurations and geometries, then you will obtain very different readings in each case. If we correct for these differences in geometry then the readings can be expressed in terms of resistivity, and you can then make more realistic comparisons of measurements made with the different probe configurations. Resistivity is representative of the bulk properties of the ground, not the probe configuration used.

Strictly speaking, the conversion is made to apparent resistivity, not just resistivity. This is because the conversion assumes the ground is entirely uniform, yet the ground is far from uniform : it usually has a layered structure, conductive topsoil lies over a less conductive bedrock etc.

H-2 Conversion to Resistivity

Four probes are used to make a resistance measurement, two current and two potential. Figure B-1 shows four such probes in a linear arrangement, C1 and C2 are current probes, P1 and P2 are potential probes. A general expression for calculating resistivity from resistance measurements is shown in figure B-1 which can be used for any probe configuration.



$$\text{Resistivity (ohm-m)} = \frac{2\pi R}{\text{G.F.}} = \frac{6.283\ R}{\text{G.F.}}$$

$$\text{where G.F.} = \frac{1}{C2\ P2} + \frac{1}{C1\ P1} - \frac{1}{C2\ P1} - \frac{1}{C1\ P2}$$

where C2 P2 = distance between probe C2 and P2 etc.

Figure B-1. Formula for conversion of resistance to apparent resistivity.

This expression can be simplified for a number of common probe configurations :

(1) Wenner :	Resistivity = $2 \pi R d$	where d = probe separation
(2) Double-Dipole :	Resistivity = $2 \pi R 3 d$	where d = probe separation
(3) Twin :	Resistivity = $\pi R d$ (approx.)	where d = mobile = remote separation
(4) Twin :	Resistivity = $2 \pi R d$ (approx.)	where d = mobile separation and where remote spacing >> than mobile spacing

In the case of the Wenner and Double-Dipole arrangements, d is the equal separation between all four probes, and will be 0.5m on a PA5 frame. The first Twin formula (3) is for the situation where the mobile and remote probe separation is equal, typically 0.5m to 2m, where the distance between mobile and remote probes is much greater. The second Twin formula (4) is for the case when the remote probe spacing is much larger than the mobile spacing, for example remote probe spacing 15m, and mobile spacing is 0.25m to 1.5m; again the distance between mobile and remote probes must be much greater than their separations. You can use this last formula (4) to calculate resistivies for Twin configuration pseudo-sections, providing the remote probes are separated sufficiently.

If we insert a typical value of 100 ohm-m (moist soil) into the above formulae, this will give an insight into how the measured resistance values may vary between probe configurations - this may useful when considering the likely dynamic range of readings for a multiplex sequence that uses several different probe configurations.

(a) Wenner :	Resistance = 31.8 ohms	where d = 0.5m
(b) Double-Dipole :	Resistance = 10.6 ohms	where d = 0.5m
(c) Twin (0.5m remotes) :	Resistance = 63.7 ohms	where mobile separation = 0.5m
(d) Twin (15m remotes) :	Resistance = 63.7 ohms	where mobile separation = 0.25m
(e) Twin (15m remotes) :	Resistance = 31.8 ohms	where mobile separation = 0.5m
(f) Twin (15m remotes) :	Resistance = 15.9 ohms	where mobile separation = 1.0m
(g) Twin (15m remotes) :	Resistance = 10.6 ohms	where mobile separation = 1.5m
(h) Twin (15m remotes) :	Resistance = 7.95 ohms	where mobile separation = 2.0m

A more general geometry for the Twin configuration is shown in figure B-2. Again, you can use the distances C2 P2, C1 P1 etc to insert in the geometry factor (G.F.) to calculate resistivity from a measured resistance value.

H-3 Remote Probe Contact Resistance.

If the contact resistance at the remote probes of a Twin configurations is high, then this can combine with the capacitance of the 50m 2-core remote probe cable to add an offset to any measured resistance value. This value will remain constant as the mobile probes are moved around. Table B-1 shows some typical values. Usually contact resistance in moist soils is of the order of 1 Kohm, providing they are well inserted, so there will then be minimal offset changes. However, in dry conditions, and contact resistance increases beyond

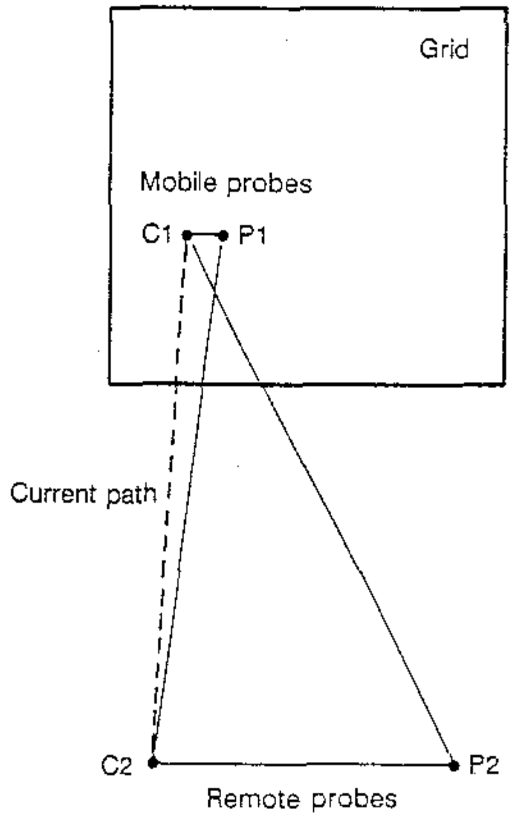


Figure B-2. Plan view of a typical Twin probe configuration.

about 5 Kohms, the offset change can become very significant compared to the measured value.

In particular, note that the offset may be positive or negative. If the separation of the mobile probes is large (say 1.5m to 2m), we would expect background resistance to be low, and if remote contact resistance is also high, then the offset might be sufficient to give negative resistance readings.

Remote Probe Contact Resistance	Reading Offset
0 Kohm	0 ohms
5 Kohm	-7 ohms
10 Kohm	-24 ohms
15 Kohm	-1 ohms
22 Kohm	Unstable

Table B-1. Resistance offset (with 50m 2-core cable) for various Twin remote contact resistances.

APPENDIX I

FURTHER READING

I-1 Introduction

The following references will provide further reading matter on resistivity surveying. Although some specific pages are listed which deal directly with resistivity surveying, most of the publications also detail other geophysical techniques which may be of interest, for example magnetometry; indeed, reading about these other techniques may well help to put resistivity surveying in its proper context.

Some older references are included for those interested in charting the progress of geophysical surveying in archaeology. Of the more recent publications, Clark's "Seeing Beneath the Soil" may be especially useful for those new to the subject area who want a non-technical introduction to the subject (it can be purchased through your local bookseller or direct from Geoscan Research in paperback form). Scollar's "Archaeological Prospecting and Remote Sensing" provides a very thorough, though much more technical description of archaeological geophysical techniques, along with associated subject areas. Those involved in a professional capacity with archaeological geophysics and evaluation will be interested in two Institute of Field Archaeology (IFA) publications : (a) Technical Paper Number 9, "The Use of Geophysical Techniques in Archaeological Evaluations"; and (b) an IFA paper "Practice and method in the application of geophysical techniques in archaeology", to be found in "Archaeological Resource Management in the UK - An Introduction". All users should put the English Heritage Standards document "Geophysical survey in archaeological field evaluation" at the top of their reading list. This is available from English Heritage or direct from Geoscan Research (free of charge). Standard text books on geological geophysical techniques include Telford, Geldart and Sheriff's "Applied Geophysics" and Keller and Frischknecht's "Electrical Methods in Geophysical Prospecting", though these require a good appreciation of mathematical techniques to be of greatest benefit. The journal Archaeometry publishes several papers associated with archaeological geophysical techniques, whilst the journal "Archaeological Prospection" publishes papers dedicated to archaeological prospection techniques, including practice, interpretation, presentation, research, new techniques, reviews and a discussion forum (details available from Geoscan Research).

Archaeological Prospection. Wiley.

Archaeometry. Cambridge University Press.

Aitken, M.J. (1974). Physics and Archaeology, 2nd Ed. Clarendon Press : 267-286.

Aspinall, A., Walker, A.R. (1975). The earth resistivity instrument and its application to shallow earth surveys. Underground Services 3 : 12-15.

Aspinall, A., Dockrill, S.J., and Pocock, J.A. - editors (1982). Geophysical Surveys 1982. School of Archaeological Sciences, University of Bradford.

Clark, A.J. (1990). Seeing Beneath the Soil - prospecting methods in Archaeology. Batsford.

David, A. (1995). Geophysical survey in archaeological field evaluation. Pub. English Heritage. Research and Professional Services Guideline Number 1.

Gaffney, C., Gater, J. with Ovenden, S. (1991). The Use of Geophysical Techniques in Archaeological Evaluations. Pub. Institute of Field Archaeologists. Technical Paper number 9.

Gaffney, C., and Gater, J. (1993). Practice and method in the application of geophysical techniques in archaeology. Archaeological Resource Management in the UK - An Introduction. Institute of Field Archaeologists : 205-214.

Keller, G.V. and Frishknecht, F.C. (1966). Electrical Methods in Geophysical Prospecting. Pergamon Press.

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

Tite, M.S. (1972). Methods of Physical Examination in Archaeology. Seminar Press : 25-32, 54-57.

APPENDIX J

INTERFERENCE

J-1 Introduction

Usually you should experience very few problems with interference and your RM4 resistance meter. However, there are some circumstance when this may be a problem and the following sections attempt to help you avoid these in the first place, or if they do occur, suggest ways of overcoming the problem.

J-2 Interference whilst Surveying

You may experience interference in the form of flickering readings during some surveys. This is more likely to be on an urban site, though some rural sites may also exhibit similar problems. Flickering is more likely to be observed with arrays that have long cable runs, such as the Twin or arrays configured using the PA3, rather than with the smaller arrays such as a 0.5m Wenner configured using a PA5. The interference is usually due to underground mains power earth currents, telephone earth return currents, or currents conducted along underground pipes, though proximity to powerful radio or television transmitters may also cause problems. It is usually a function of the distance between the potential probes, rather than actual cable length.

Firstly, try to improve the signal to noise ratio by setting the Filter switch to the Urban setting. This will switch extra filtering into the RM4 signal path which is not present with the Rural setting.

If you are using a Twin array then try moving the remote probes to a different location, 90 degrees or 180 degrees with respect to the current position. Try to reduce the distance between the mobile and remote probes, though see sections 5-6 and 5-7 for advice on the minimum allowable distance. If you are using a PA3 with wide spacing consider rotating the array through 90 degrees.

Interference is most likely to be observable with the most sensitive ranges (200.0 ohms and 20.00 ohms). To improve signal to noise ratio, consider whether you need the extra resolution - if not, switch to a less sensitive range. However, depending on the ground resistivity, probe array configuration, and required reading resolution, it may not be possible to change the range setting. In this case you should consider another probe configuration which has a smaller distance between the potential probes. For example, if you experience problems with the Twin array, and have a PA5 probe array available, then consider configuring this either as a four probe Wenner or Double-Dipole array, section 2-4(5). If you do not have the extra medium length wings or struts to give this width then configure a mini-Schlumberger using just the standard frame with short wings, section 2-4(5).

APPENDIX K

CONNECTIONS FOR EARLY PA5 FRAMES

K-1 Introduction

If you have an early version of the PA5 then some of the jump lead connection details presented in section 2 are not directly applicable. (Early versions of the PA5 used a central 0.6m aluminium beam and jumper leads were plugged into two groups of three terminals, positioned at either end of the beam). All the beam colour coding specified is the same for both early and present PA5 systems, but due to the different location of the terminals for the jump leads, lead lengths (and hence their identifying colours) will be different. This appendix presents some corresponding illustrations and tables applicable to the earlier PA5 system.

If you have the current version of the PA5, which uses a wooden central beam and junction box attached to the frame, then you can follow the instructions presented in section 2 directly, and ignore this appendix.

K-2 Replacement Tables and Figures

Colour	Jump Lead Length	Basic PA5 Quantity	Full Kit Quantity
Black	150 mm	2	2
Red	500 mm	2	3
Green	750 mm	0	2
Blue	1000 mm	0	2
Yellow	1250 mm	0	1
White	1500 mm	0	1

Table 2-2. PA5 Jump lead lengths and colours.

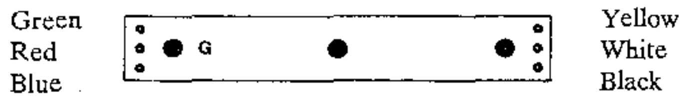


Figure 2-10. Socket positions for jump leads on the main frame.
G shows the cable gland position.

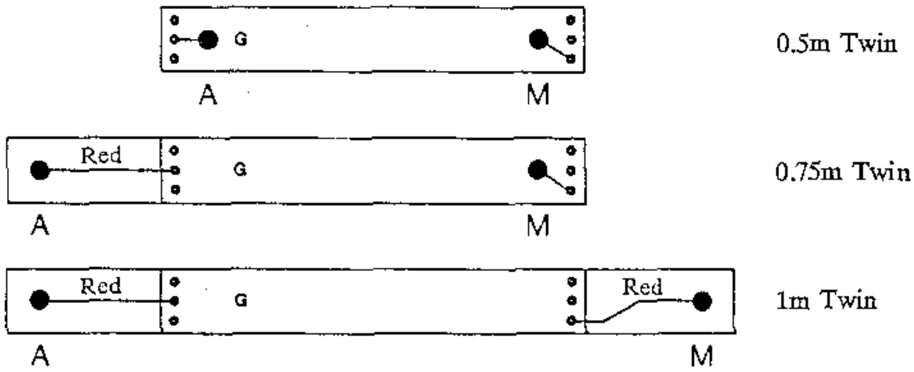


Figure 2-11. Wing, probe and jump lead positions required to configure a 0.5m, 0.75m or 1m Twin Electrode Array with an AD1 adapter.

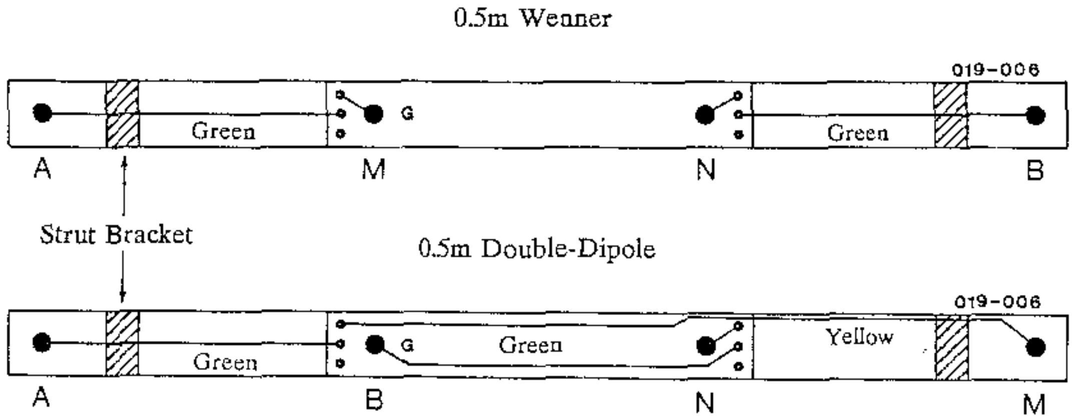


Figure 2-12. Wing, strut, probe and jump lead positions required to configure a 0.5m Wenner or 0.5m Double-Dipole with an AD3 adapter.