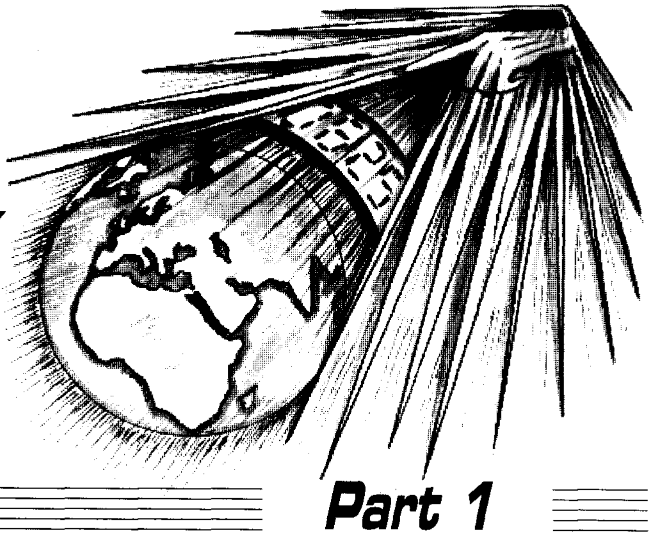
Constructional Project

EARTH RESISTIVITY METER



ROBERT BECK

Part 1

Your assistance to the local Archeological Society could be invaluable with this simple subterranean site detector at your command.

RESISTIVITY surveying is a method of detecting subterranean features and has been an investigative technique of archaeologists for many years. Archaeological features can often be detected when buried about one metre under the present ground level. Natural features such as gravel or peat beds buried under silt can be detected at much greater depths.

The same survey will detect both natural and archaeological features. In general, the former tend to have ill-defined "soft" edges whilst the latter consist of geometric "man-made" shapes; if it "looks like" the outline of a building, it probably is!

HISTORICAL BACKGROUND

The technique of resistivity surveying was first used by Civil Engineers for investigating the proposed sites of dams, etc. Archaeologists first realised its potential in 1946. These early instruments were powered by hand cranked a.c. generators and used a resistance bridge configuration to perform measurements, similar to the early "Megger" insulation test sets, although the latter used d.c.

The readings were taken by simultaneously winding the generator handle and reading a meter calibrated in Ohms. As a series of readings across a site was required, the procedure was slow and tedious. With the arrival of the transistor, resistivity sets designed specifically for archaeology gradually became quicker to operate.

Early transistor sets progressed through an a.c. bridge configuration, which had to be balanced with a calibrated potentiometer for each reading, to the present commercial instruments which are designed to log the readings directly into a data logger, displaying results in the form of a map on a portable computer in the field.

It is interesting to note in passing that resistivity measurements have recently been used for crack measurement in metals and also in medical applications.

WHAT IS RESISTIVITY?

Resistivity is defined as the resistance of a metre cube of material across opposite faces. It is therefore a standardised way of comparing resistances of various materials:

$$\rho = RL/A$$

Where:

ρ = resistivity
R = resistance of material along its length
L = length
A = area of cross section

The principle upon which resistivity surveying works is as follows:

The resistivities of stone, concrete and similar materials are relatively high, whilst the resistivities of nearly all soils are relatively low. Often ditch and pit fillings, which can no longer be seen on the surface, have an even lower resistivity than the surrounding soil.

The combined resistivity of soil and any included material is termed the *apparent resistivity*. If we measure the resistivity across an area of ground that has a stone block buried somewhere in it, the apparent resistivity will increase at that particular point. Similarly, if we cross the site of a silted-up ditch, the reading will decrease, as illustrated in Fig. 1.

We therefore have a method of detecting building foundations, walls, silted-up ditches and pits, etc. However, various

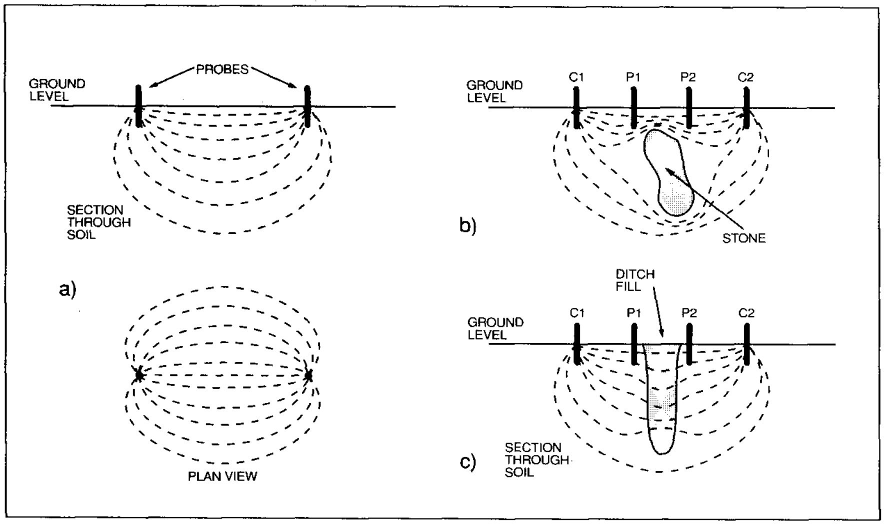
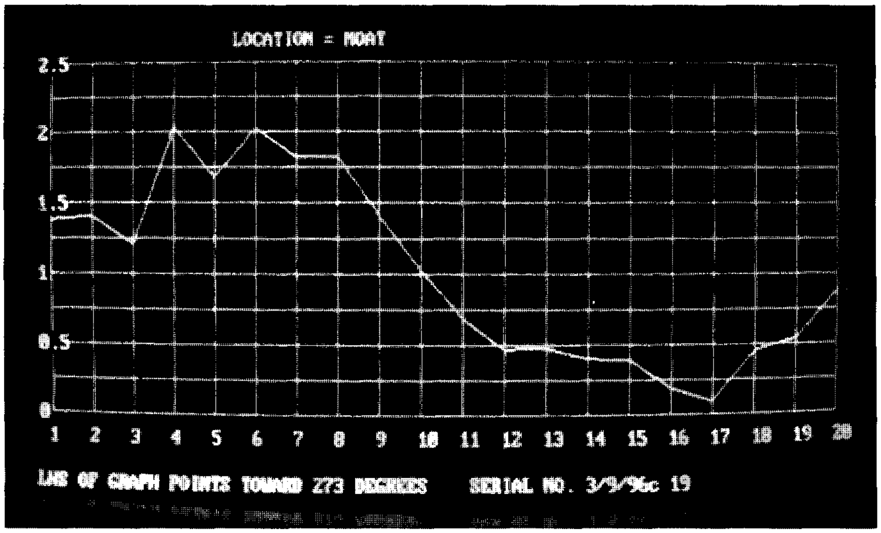


Fig. 1. Current paths set up by probe arrays: (a) current flow between two probes; (b) Wenner (see "Probe Configurations") array with stone below it; (c) Wenner array with ditch below it.



One way of analysing the sample results is to view them as a linear graph on a computer screen.

factors complicate the issue: the resistivity of soil depends upon its actual composition, the moisture present and the amount of compaction.

It therefore follows that taking just one or two readings over a site is meaningless and will convey no useful information to the operator. A series of readings must be methodically taken according to a prearranged plan.

The resistivity meter requires a system of probes pushed into the soil to a depth of about 250mm to make its measurements. Resistivity surveying can therefore be considered a non-destructive technique that will not harm an archaeological site – *providing that you do not dig the site to check your results!*

It is stressed that digging at sites of potential archeological interest should only be carried out under the supervision of suitably qualified archeologists. Advice on the ethics of amateur resistivity surveying, and about joining Archeological Societies, is given in Part 2, next month.

SOME PROBLEMS

Why can we not make earth resistivity measurements using the Ohmmeter that we already possess in our toolbox? It might be thought that a simple multimeter switched to a suitable Ohms range would be the most cost effective solution to resistivity measurement.

However, these meters use d.c. to perform resistance measurements. This presents some difficulties. The multimeter will respond to the following:

1. 50Hz mains derived currents circulating in the ground
2. "Battery effect", caused by chemical interaction between probes, and acids or alkalis naturally occurring in soils
3. Electrolytic effect of the measuring current passing through the soil.

The first two points are self explanatory but the third may need some clarification.

The electrolytic effect will cause a gradual increase in the contact resistance between the probes and the soil, making the reading on the multimeter gradually rise. This increase in contact resistance is caused by a film of gas coating the probes, due to water in the soil breaking down into its constituent parts of oxygen and hydrogen under the influence of the measuring current. Try this experiment:

Connect a multimeter, set to the Kilohms range, to two probes pushed into the ground about 200mm deep and 500mm apart. The probes can be pieces of welding rod, metal pipe, etc. Then switch the multimeter on and record the resistance readings against time.

You can see in Table 1 that the readings tend to increase with time and never quite settle down. This demonstrates the electrolytic effect of the measuring current.

Table 1

Time	Kilohms	Kilohms (leads reversed)
0 sec.	6·36	9·66
10 sec.	6·66	10·00
20 sec.	6·76	10·15
30 sec.	6·81	10·28
40 sec.	6·87	10·34
50 sec.	6·91	10·40
1·0 min.	6·95	10·44
1·5 min.	7·06	10·53
2·0 min.	7·17	10·57
2·5 min.	7·23	10·59
3·0 min.	7·23	10·63
3·5 min.	7·30	10·66
4·0 min.	7·30	10·69
4·5 min.	7·28	10·70
5·0 min.	7·36	10·72

It can be seen from the results columns that reversing the leads gives a totally different set of increasing readings. This is the result of the "battery effect" combined with the electrolytic effect.

Change the multimeter to the Millivolts D.C. setting and you will see a reading of, for example, 150mV, which demonstrates the "battery effect". Set the multimeter range to the Millivolts A.C. setting and a reading of, probably, 3mV to 4mV will be observed, thus indicating mains derived circulating currents.

Having now noted these complications we can consider ways of overcoming them.

SYSTEM REQUIREMENTS

An a.c. square wave oscillator needs to be used for supplying current to the soil. The frequency must not be too low or the electrolytic effect will become noticeable. Equally, the frequency must not be too high or ground inductive effects will become apparent. The frequency must not be a multiple of 50Hz otherwise we cannot use a synchronous rectifier at a later stage to remove unwanted 50Hz signals. The author's preference is to use 137Hz.

The oscillator is used to feed a constant current generator which enables a fixed current to be delivered to the soil, thus avoiding at least one variable. This current is fed into the soil via a pair of probes, known as the C_1 and C_2 probes.

The resultant voltage is picked out of the soil by a second pair of probes, known as the P_1 and P_2 probes and is a "floating" voltage in that neither probe is at the instrument's 0V rail voltage.

This necessitates the use of a differential amplifier because neither input terminal of the input amplifier can be connected to earth. The input impedance of the differential amplifier should be as high as practical so as to swamp any contact resistance associated with the P_1 and P_2 probes.

The output of the amplifier then goes to a synchronous rectifier so that only those signals which are in phase with the oscillator are rectified. The rectified signal can now be fed to a digital multimeter which makes a convenient readout device. The block diagram in Fig. 2 illustrates the principle.

Any cube of soil that we wish to measure does not exist in isolation, it is part of the whole earth. Therefore the adjacent soil also helps to conduct the current. If a pair of probes is inserted into the soil, the current between them tends to fan-out in all directions, gradually weakening as it spreads further from the centre line between the probes (see Fig. 1a).

The effect is analogous to that which can be seen when iron filings are used to trace the lines of force of a bar magnet. In the case of the soil cube, the electrons, being similarly charged, repel each other, to cause the fanning out of the current.

It is possible to connect an a.c. measuring device directly across the probes which

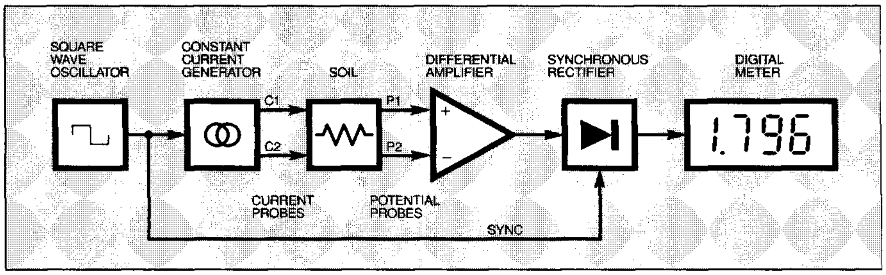


Fig. 2. Block diagram for a basic earth resistivity meter.

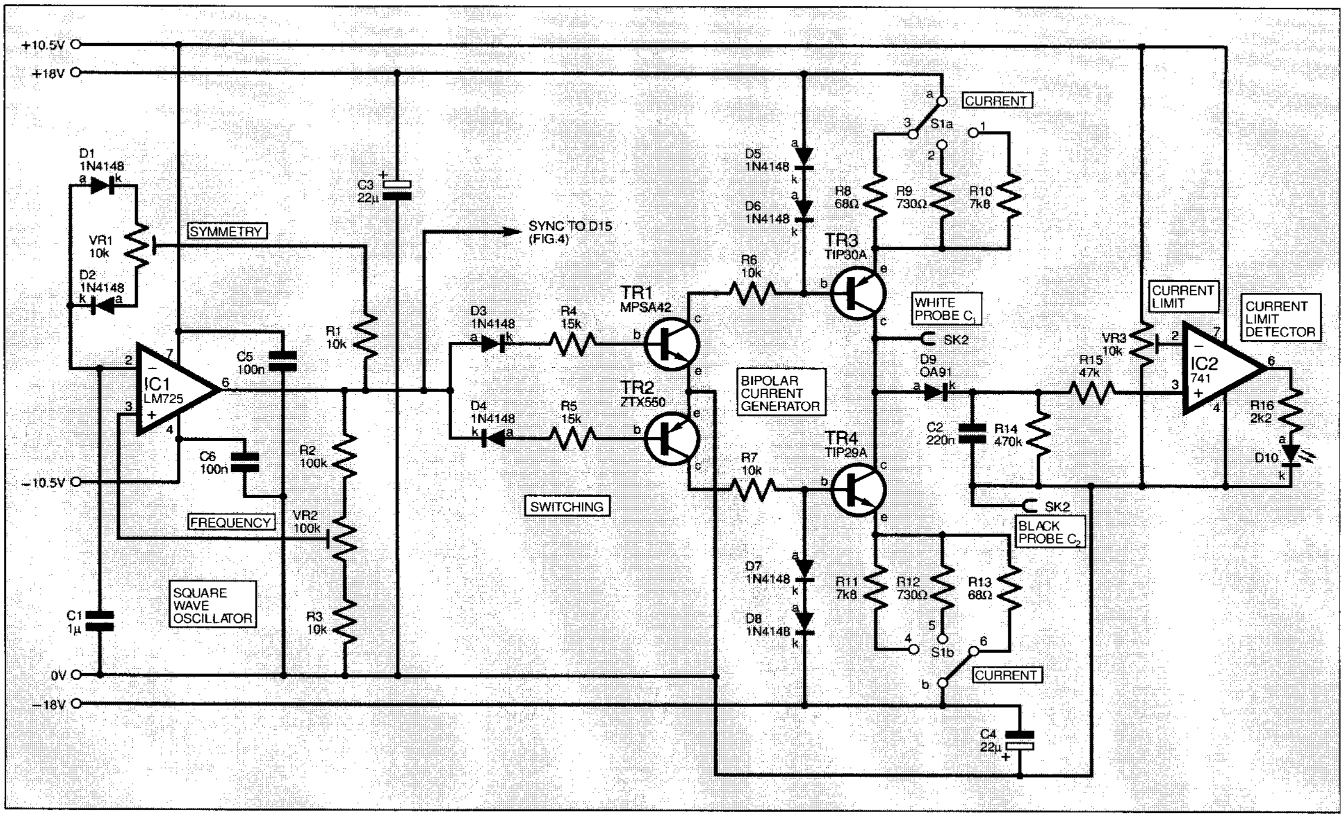


Fig. 3. Circuit diagram for the Current Generator.

are injecting the a.c. into the soil. We would have enough data to calculate the resistance between the probes using Ohm's Law, i.e. R = V / I.

This method does work but it has one major problem in that we are measuring voltage at either end of a hemisphere of current. If we introduce two separate electrodes and use them only for "picking off" a voltage, we have an electrode system that is more depth sensitive.

The reason for this is that, in the case of two probes only, we are measuring the effect of the current mainly running along the surface of the soil. Whereas, in the case of two pairs of probes, we are not measuring the effect of the current that is off the probes' horizontal axis to such a great extent, thereby forcing the probe configuration to be more depth sensitive compared to surface sensitive.

The potential difference being measured is on the flat surface of a hemisphere, not across the opposite faces of a cube. Therefore it follows that we are not calculating actual resistivity, which depends on the particular probe configuration in use. However, there is no need to calculate true resistivity figures, because only relative readings are required.

CIRCUIT DESCRIPTION

Having looked at a bit of theory, let's get right down to earth and describe the circuit for a simple Earth Resistivity Meter. The circuit diagram for the first part of it, the Current Generator, is shown in Fig. 3.

Op.amp IC1, together with its associated components, forms an oscillator giving a square wave output which is balanced about the 0V line, and at a frequency of 137Hz. The output appears at pin 6, with its amplitude being a little below the 10·5V supply rails.

The symmetry of the waveform is accurately set by preset potentiometer VR1 in conjunction with diodes D1 and D2. The precise frequency is set by preset VR2. Capacitor C1 forms part of the time constant for the oscillator.

A non-polarised polyester capacitor *must* be used for C1. It should *not* be an electrolytic capacitor as this would have a certain amount of leakage current, which may vary with temperature, and cause the oscillator to drift from the desired frequency.

The output at IC1 pin 6 is passed to the switching circuit, formed around transistors TR1 and TR2, which "enables" either the positive or negative half of the bipolar current generator, as appropriate. Positive constant current is generated by TR3 in conjunction with diodes D5 and D6, and selectable emitter load resistors R8 to R10. Negative constant current is similarly generated by the circuit around TR4, D7, D8 and switched resistors R11 to R13.

Selection of the emitter loads is carried out by the dual 3-way switch S1a/b. The output current range is selectable at 0·1mA, 1mA or 10mA, in order of switch positions 1 to 3.

The selected current is available directly as an output at the collectors of TR3 and TR4, via socket SK1. The amount of current being delivered is detected by the circuit around IC2, which is, in fact, actually a voltage level detector. The voltage level is, of course, relative to the current being drawn via SK1.

Diode D9, resistor R14 and capacitor C2 form a rectifier and smoothing circuit. Op.amp IC2 is configured as a comparator, with preset VR3 providing the reference voltage.

When the voltage across the current output goes to too high a value, indicating that the current generator is feeding into too high a load, l.e.d. D10 will light. This indicates that an erroneous reading is occurring, because there is insufficient voltage available to drive the demanded current.

In this case, the Current switch, S1a/S1b, should be set to a lower value which would accept a higher load resistance.

The voltage drop in the soil caused by the current driven through it is detected by the P_1 and P_2 probes, which feed their signals to a Differential Input Amplifier comprising IC3a, IC3b, IC4a and IC4b, as seen in Fig. 4.

Over-voltage protection for the dual amplifier IC3 is provided by Zener diodes D11 to D14. Being 9·1V diodes, any voltage between the probe and earth that is above 9·1V will cause one of the diodes to conduct, thus protecting the amplifier.

Amplifier gain is set by selecting one of three resistors, R23 to R25, by the Gain switch S2. The gain may be calculated from the following formula:

$$\text{Gain} = 1 + (2R_{FEEDBACK}/R_{SWITCH})$$

thus:

$$\text{Gain} = 1 + (2 \times 10000/R_{SWITCH})$$

The resistors chosen give switched gains of × 10, × 100 and × 1000.

The amplified signal is passed to IC4b, which acts as a Synchronous Rectifier. A reference signal is obtained from pin 6 of IC1 (Fig. 3) and fed to diode D15. When the cathode (k) of D15 is positive, no voltage will be applied to the gate (g) of field effect transistor (f.e.t.) TR6. This will cause

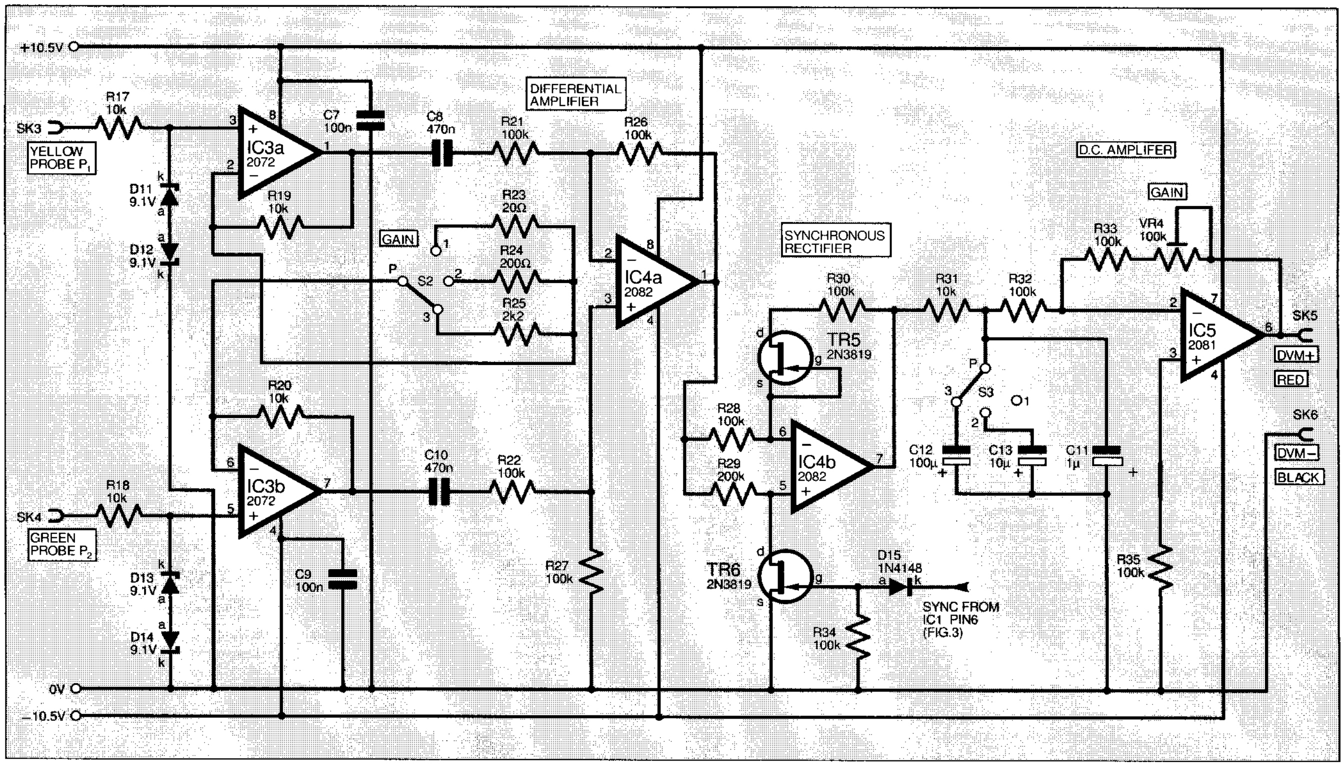


Fig. 4. Circuit diagram for the Differential Input Amplifier, Synchronous Rectifier and D.C. Amplifier.

the f.e.t. source-drain (s-d) path to conduct, thus grounding input pin 5 of IC4b.

The circuit then acts as an inverting amplifier with a gain of − 1. Its input pin 5 is damped by resistor R29 which, because of its high resistance compared to the output impedance of the last stage, will cause no noticeable loading.

When the cathode of D15 is negative, the gate voltage of TR6 will be about − 11V and the f.e.t. source-drain path will be high impedance, and so act as an open circuit. The circuit will then act as a non-inverting amplifier with a gain of + 1.

Basically, the gain is determined by the relative values of resistors R28, R29 and R30. The inclusion of the f.e.t. TR5 in the feedback path helps to stabilise any tendency towards gain-change caused by temperature drift.

When the input signal to the Synchronous Rectifier (via D15) is positive, the output will be the same amplitude as the input, but will be reversed in polarity. When the input signal is negative, the output signal will also be negative, but still having the same amplitude as the input.

The rectified signal at IC4b pin 7 will always be negative, with any signals that are out of phase with the oscillator being superimposed as an a.c. waveform on the d.c. output signal.

The output from IC4b pin 7 is passed through a low-pass filter consisting of resistors R31, R32, and capacitors C11 to C13. This will remove most of the unwanted a.c. signals that are present. C12 and C13 can be switched in or out of the circuit by S3, so allowing the filter response times and effectiveness to be changed.

However, increasing the effectiveness of the filter by increasing the value of either of these capacitors will slow the response time of the circuit. The values chosen represent a suitable compromise for minimising the interference found in most rural locations.

The output from the D.C. Amplifier IC5 is then fed via sockets SK5 and SK6 to a digital voltmeter (DVM). A toolbox type digital multimeter, set to a relevant voltage range, is suitable, with connecting leads of about 500mm in length. If desired, a digital panel meter may be incorporated in the case containing the resistivity meter. It did not seem to be a cost effective exercise to build a digital indicator for this circuit.

Whatever type of indicator is used, it should have ranges from 0V to 10V d.c., down to 0V to 100mV f.s.d. (full scale deflection).

POWER SUPPLY

As shown in Fig. 5, power is supplied by two batteries, B1 and B2, which may be any type of battery that can supply 18V at only a few milliamps. Rechargeable NiCad cells stripped from old radio equipment have been found to be ideal! An alternative suggestion is two PP9 batteries in series for B1, and a similar arrangement for B2.

The twin power supplies are regulated down to + 10·5V and − 10·5V by IC6 and IC7, in conjunction with Zener diodes D16 and D17.

CONSTRUCTION

These circuits are built on two printed circuit boards, whose details are shown in Fig. 6 and Fig. 7. The boards are available from the *EPE PCB Service*, code 131 (Current Gen.), 132 (Amp/Rect.).

It is recommended that d.i.l. (dual-in-line) sockets should be used for all the integrated circuits (i.c.s). Mount the resistors, diodes and capacitors first, followed by the transistors and i.c.s. Correctly observe the polarity of all but the resistors.

Prepare a suitably sized diecast case by drilling holes for the sockets, p.c.b. fixing holes and switches. Mount these components and instal the p.c.b.s using 6BA

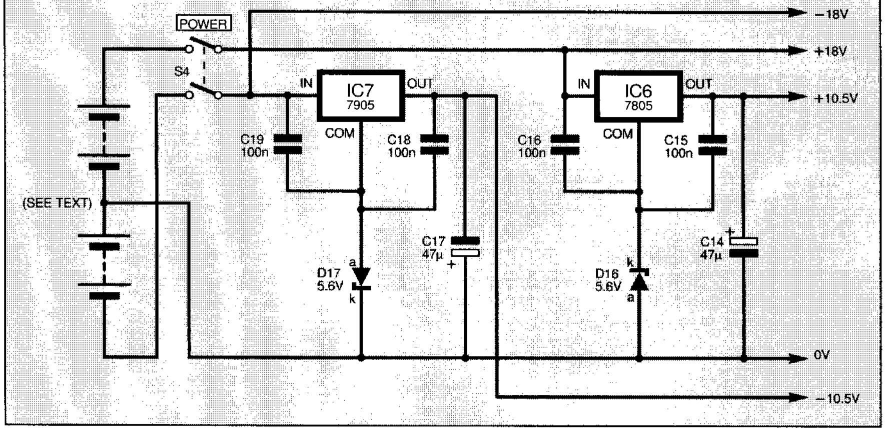


Fig. 5. Power supply circuit diagram.

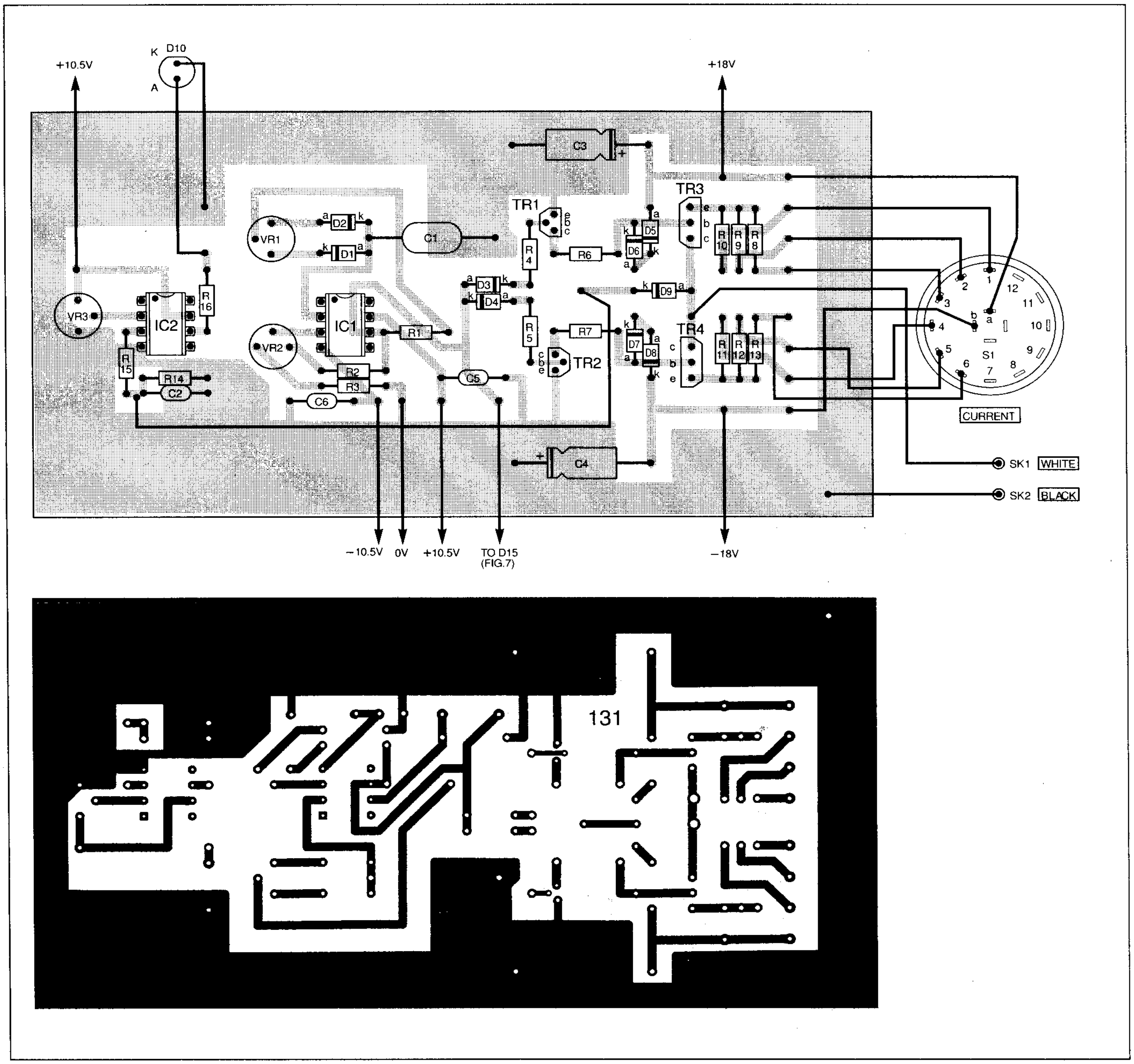
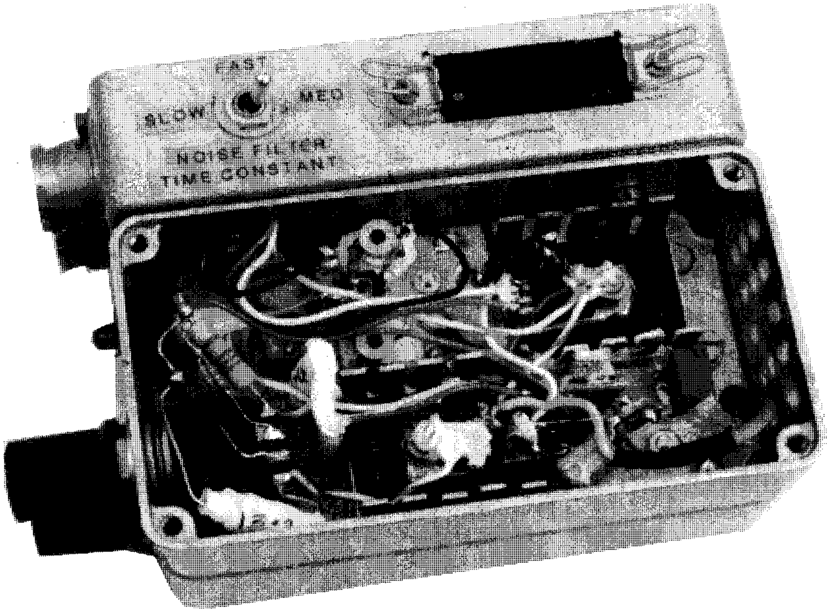


Fig. 6. Details of the component layout and full size underside copper foil track master pattern for the Current Generator p.c.b.

nuts and bolts, or sturdy p.c.b. mounting pillars.

The prototype of this circuit was actually constructed on stripboards which were mounted in three small diecast cases, each measuring 60mm × 110mm × 30mm, each one being bolted to the other with 6BA nuts and bolts.

However, with the p.c.b. design shown, only one box needs to be used; a suggested minimum size is about 140mm × 70mm × 60mm. Double-check the size of your assembly before buying a case, since individual component sizes may vary depending on the source. You might consider buying a diecast case with a rubber gasket round the lid to help minimise the risk of water ingress when out in the field!



The author's prototype, built on stripboard and mounted in three combined boxes.

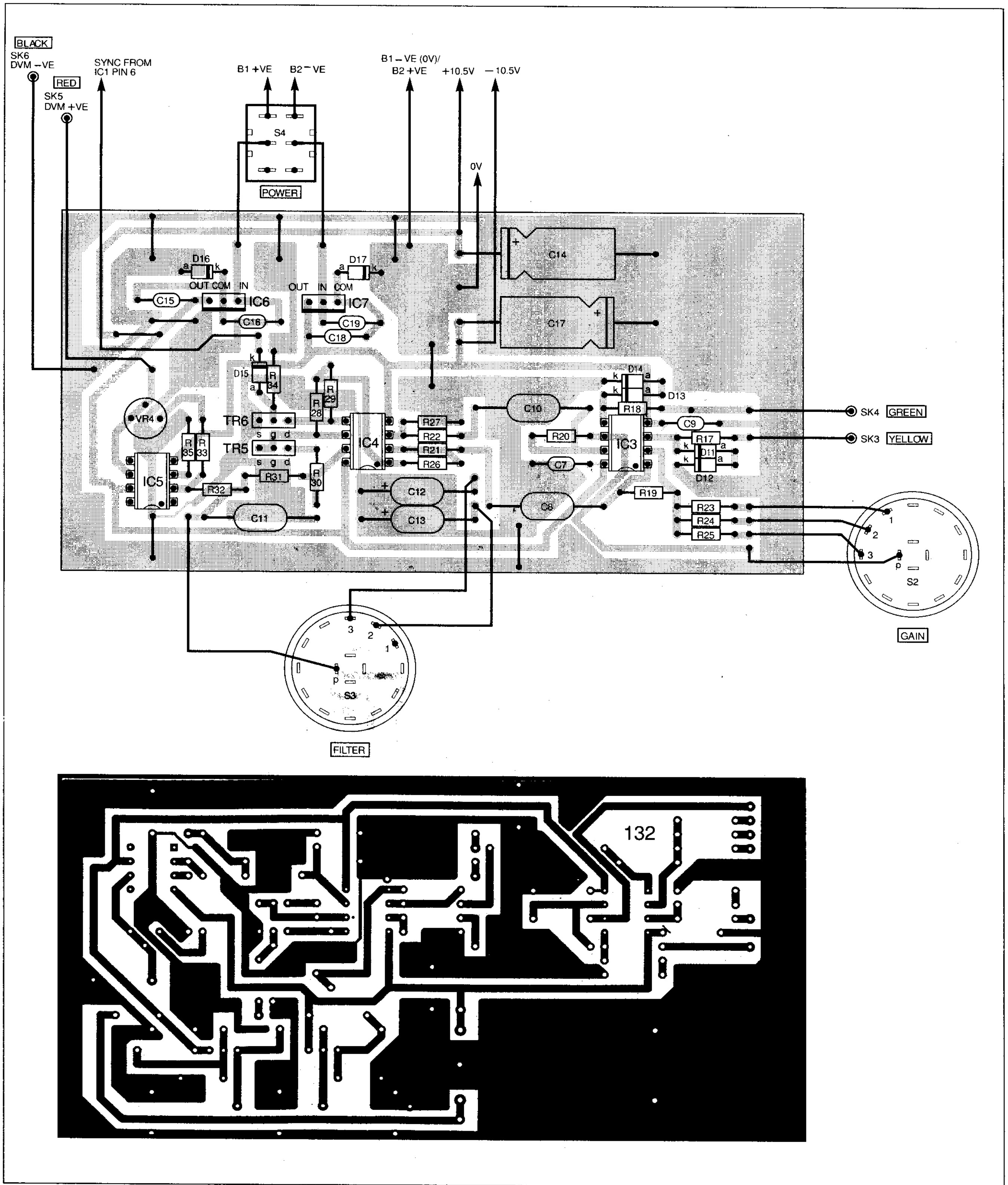


Fig. 7. Details of the component layout and full size underside copper foil track master for the Amplifiers and Rectifier p.c.b.

ADJUSTMENTS

If you have an oscilloscope and frequency meter, proceed as follows:

1. Switch on. Measure the positive supply line at C15 $+V_e$ and check that it is +10·5V. Measure the negative supply line at C17 $-V_e$ and check that it is −10·5V.

2. Connect a frequency meter to IC1 pin 6 and set VR2 to give an output of 137Hz. If no frequency meter is available, use a medium impedance earpiece connected between IC1 pin 6 and the 0V line and estimate a suitable tone, i.e. a little above 100Hz (rectified mains hum frequency).

3. Connect an oscilloscope to IC1 pin 6 and set VR1 so that both halves of the square wave are the same. Ascertain that the amplitude is about 11V, and that it is symmetrical about the 0V line. If no oscilloscope is available, set VR1 mid-way.

4. Temporarily connect a test resistor across the C_1 and C_2 terminals. Select the test resistor value and current generator output according to Table 2. Connect the

Table 2

Current Setting	Test Resistor
0·1mA	10kΩ
1mA	1kΩ
10mA	100Ω

COMPONENTS

Resistors

R1, R3, R6, R7, R17 to R20, R31	10k (9 off)
R2, R21, R22, R26 to R28, R30, R32 to R35	100k (11 off)
R4, R5	15k (2 off)
R8, R13	68Ω (2 off)
R9, R12	730Ω (2 off)
R10, R11	7k8 (2 off)
R14	470k
R15	47k
R16, R25	2k2 (2 off)
R23	20Ω
R24	200Ω
R29	200k

All 0·6W 1% metal film

See SHOP TALK Page

Potentiometers

VR1, VR3	10k horiz. preset (2 off)
VR2, VR4	100k horiz. preset (2 off)

Capacitors

C1	1µ metallised polyester, 100V
C2	220n disc ceramic, 25V
C3, C4	22µ axial elect. 63V (2 off)
C5 to C6, C7, C9, C15, C16, C18, C19	100n disc ceramic (8 off)
C8, C10	470n polyester (2 off)
C11	1µ tantalum bead, 35V
C12	100µ axial elect. 35V
C13	10µ axial elect. 35V
C14, C17	47µ axial elect. 35V (2 off)

Semiconductors

D1 to D8, D15	1N4148 silicon signal diode (9 off)
D9	OA91 germanium signal diode
D10	red l.e.d.
D11 to D14	BZY88C9V1 9.1V 500mW Zener diode (4 off)
D16, D17	BZY88C5V6 5.6V 500mW Zener diode (2 off)
TR1	MPSA42 *npn* transistor
TR2	ZTX550 *pnp* transistor
TR3	TIP30A *pnp* high power transistor
TR4	TIP29A *npn* high power transistor
TR5, TR6	2N3819 *n*-channel f.e.t. (2 off)
IC1	LM725 op.amp
IC2	741 op.amp
IC3	2072 dual op.amp
IC4	2082 dual op.amp
IC5	2081 op.amp
IC6	7805 +5V 1A voltage regulator
IC7	7905 −5V 1A voltage regulator

Miscellaneous

B1, B2	18V battery – see text (2 off)
S1 to S3	4-pole 3-way rotary switch (3 off)
S4	d.p.d.t. toggle switch
SK1	4mm socket, white
SK2, SK6	4mm socket, black (2 off)
SK3	4mm socket, yellow
SK4	4mm socket, green
SK5	4mm socket, red

Printed circuit boards, available from the *EPE PCB Service*, codes 131 (Current Gen.) and 132 (Amp/Rect.); 8-pin d.i.l. socket (5 off); 4mm plugs, qty to suit; knob (3 off); case (see text); probe materials (see text); nuts, bolts and washers; connecting wire, solder, etc.

Approx Cost Guidance Only **excl. case and probes** **£48**

Table 3

Gain	Load	Output
× 10	10Ω	0·1V
× 10	100Ω	1V
× 10	1000Ω	10V
× 100	1Ω	0·1V
× 100	10Ω	1V
× 100	100Ω	10V
× 1000	0·1Ω	0·1V
× 1000	1Ω	1V
× 1000	10Ω	10V

oscilloscope across the resistor (scope probe tip to C_1). The oscilloscope should show a 137Hz trace at approximately ± 1V, symmetrical about the 0V line, at all three settings of current selector switch S1.

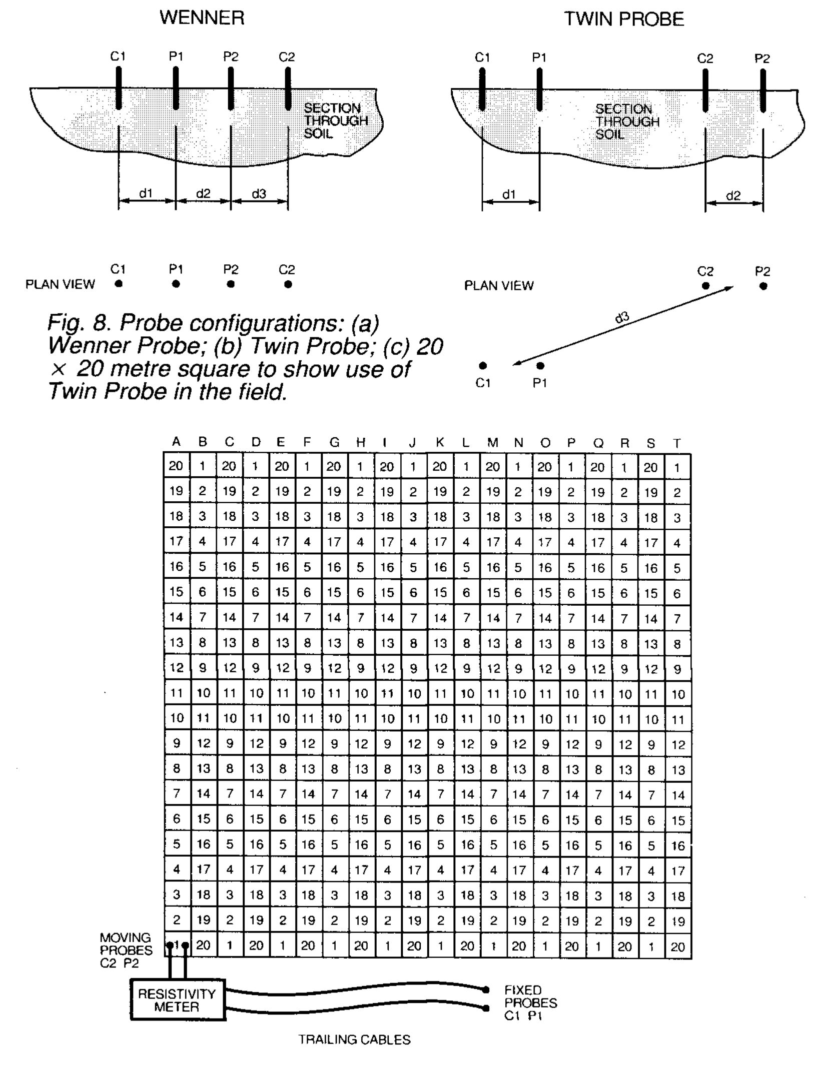
If any discrepancy is noted, the appropriate resistor (R8 to R13) on switch S1 should be checked. These resistors may be made up with a series and/or parallel connection of more than one resistor if a high degree of accuracy is desired.

5. Set the test resistor to 10Ω. Set the amplifier gain switch (S2) to × 100. Adjust preset VR4 for a d.c. output of exactly 1V across SK5 and SK6.

6. Connect P_1 to C_1, and P_2 to C_2. Connect a resistance box or a series of fixed resistors between P_1 and P_2. Set the amplifier gain (S2) and the resistance box to the figures in Table 3 and check that the output is correct.

7. Set the test resistor to 10kΩ and switch S1 for a current output of 1mA. Adjust preset VR3 until the l.e.d. D10 just lights.

This completes the tests and adjustments. Let's now probe deeper:



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

Fig. 8. Probe configurations: (a) Wenner Probe; (b) Twin Probe; (c) 20 × 20 metre square to show use of Twin Probe in the field.

PROBE CONFIGURATIONS

Now let's look at some probing factors before considering the probes themselves.

There are several probe configurations that may be used, but the two that are now widely employed are the Wenner and the Twin Probe:

Wenner configuration

In the Wenner configuration, as illustrated in Fig. 8a, all probes are equally spaced in a straight line. A spacing of about one metre being suitable for general use. The two outer probes being C_1 and C_2 with the two inner probes being P_1 and P_2.

The Wenner is suitable for linear traverses to check a site for anomalies (readings caused by buried features) before a more detailed survey is carried out.

To convert instrument readings for this configuration to resistivity, use the following formula:

$$\rho A = 2\pi dV/I$$

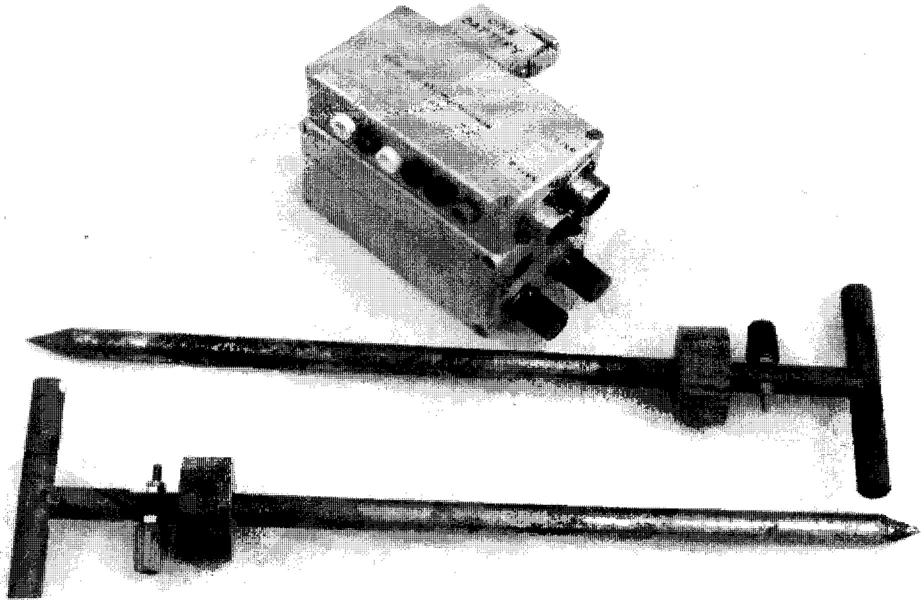
where:

ρA = apparent resistivity
d = probe spacing
V = indicated voltage divided by the amplifier gain.
I = current

Twin Probe configuration

In the Twin Probe configuration, as illustrated in Fig. 8b, probes C_1 and P_1 are inserted just off the area to be surveyed and are known as the fixed pair. Probes C_2 and P_2 are moved across the area to be surveyed as a pair at the same distance apart.

This moving pair is placed in the squares of a grid previously laid out with strings or measuring tapes, as represented in Fig. 8c.



Two of the short probes alongside the author's prototype model.

The spacing of the C_1 and P_1 probes should equal that of the C_2 and P_2 probes and be about 500mm. The spacing between the fixed pair and the moving pair can be anywhere between 15 metres and 50 metres.

Probes C_2 and P_2 may be fixed to a frame (as shown next month, for example), complete with the electronic unit to make a very easy to use setup.

To convert instrument readings for this configuration to resistivity, and referring to Fig. 8b, use the following formula:

$$\rho A = (2\pi V / I) \times (1 / ((2 / d1) - (2 / d3)))$$

Construction of the probes themselves is very simple; none of the materials or their dimensions are critical and may be dictated by what is to hand.

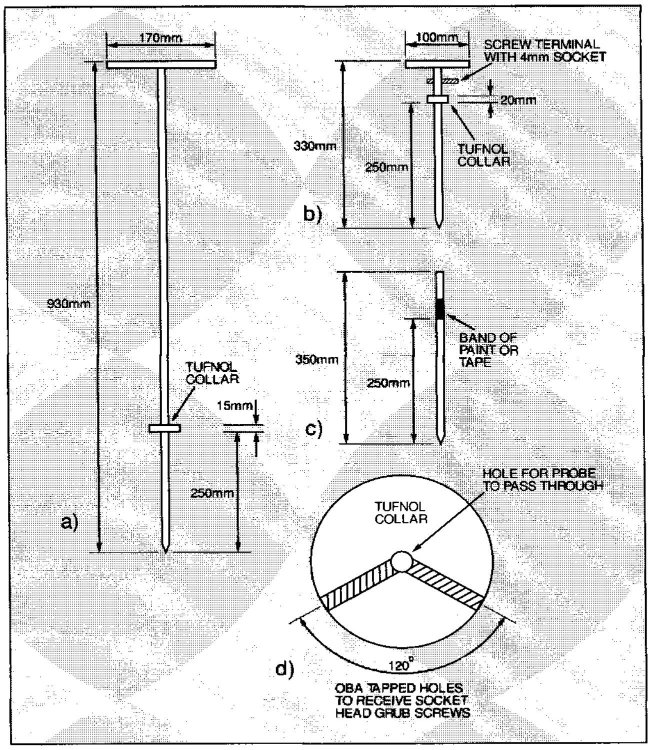
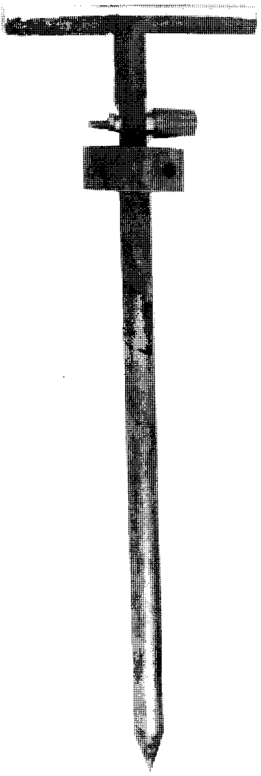


Fig. 9. Construction details of the probes: (a) long probe; (b) short probe; (c) simple probe; (d) detail of depth stop.



In Fig. 9a is shown a substantial probe that is made out of stainless steel tubing with a brazed on T-handle and tip which assists in soil penetration. This probe is designed to be used with the operator in a standing position.

A set of four probes made up as in Fig. 9a make ideal Wenner probes because, as this configuration needs to be continually moved, tall probes avoid bending the back.

A smaller version of Fig. 9a is shown in Fig. 9b; this has a 4mm screw terminal added, an alternative method of wire connection. Probes may be constructed of materials other than stainless steel, which is expensive and a little difficult to procure.

An extremely simple probe is shown in Fig. 9c and which may be constructed from 6mm diameter metal rod, i.e. brazing or uncoated welding rod, mild steel, silver steel, etc. A depth guide consisting of a band of paint or insulating tape is added and connections are made to the top of the rod with a crocodile clip.

The depth stop illustrated in Fig. 9d is adjustable by means of an Allen key. The material need not be insulating, and could be of metal if desired.

PART TWO

In the concluding article next month, the techniques and ethics of earth resistivity surveying will be discussed.

QBASIC PROGRAM

A copy of the author's program – for displaying graphics of the earth resistivity results – written in QBasic (for a PC-Compatible computer), is available from the Editorial Office for the sum of £2·50 UK, £3·10 overseas surface mail or £4·10 airmail. This is to cover admin costs and postage, the disk itself is *free*. You are welcome to copy this program and give it to your friends. See *PCB Service* for ordering details.

The program can also be downloaded *free* from our FTP site: **ftp://ftp.epemag.wimborne.co.uk**, in the sub-directory: **pub/PICS/Earth.Meter**.