ATMOSPHERIC ELECTRICITY DETECTOR by KEITH GARWELL - Part 1

Investigate Nature's power-house with this intriguing experimental design.

It all started way back at the very beginning of the 1990s when the author saw an article in an astronomy magazine suggesting that it might be possible to detect the advent of a meteor by means of a change in the earth's electric field.

Whilst he never succeeded in doing this, confessing that it might be due to inadequacies in his equipment or design, detecting and measuring changes in the electrical state of the earth's atmosphere soon became an interesting hobby.

SCENE SETTING

The ionized layers of the atmosphere extend from about 40km to 200km (25 to 125 miles) above the earth. This ionization is caused by the "Solar Wind" passing the earth and leaves the upper atmosphere positively charged.

There is thus an electric field between the upper atmosphere and the earth. Using suitable instruments, this field can be detected as it results in a minuscule current through the atmosphere.

If a probe, consisting of a metal plate, is supported on an insulator one meter above ground the metal plate will acquire by conduction the same potential as exists at this level above ground. This would be true of any height, of course, but the meter is a nice standard unit.

A potential of around 100 volts is often present. In other words there is often a potential of 200 volts or more between your nose and toes! Of course nobody gets electrocuted because the resistance of the air is so high that only a very tiny current is present. This is why the actual values are so difficult to measure.

Modern operational amplifiers make it possible to measure the tiny currents but they object strongly to being subjected to such high voltages!

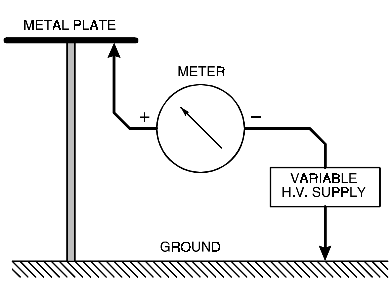


Fig.1. Basic principle of atmospheric electricity monitoring.

PRACTICAL MEASUREMENT

There is a way round this problem, as is illustrated in Fig 1. The metal plate is supported one meter above the ground and is connected to the positive terminal of a meter, which will indicate at least one picoamp. The negative side of the meter is connected to a variable high voltage supply, the other side of which is connected to ground.

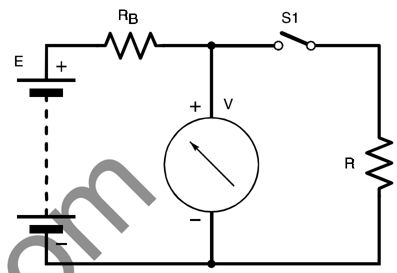


Fig.2. Equivalent circuit of Fig.1 in which atmospheric resistance can be measured.

If the power supply is now adjusted so that the current through the meter is zero, then the voltage from the power supply must be the same as the voltage on the plate.

We can also consider the plate as though it were a battery. Remembering school physics, a battery has potential and also internal resistance. Fig.2 suggests the arrangement whereby both these figures can be determined. The battery voltage is E volts and its internal resistance is R_B (the resistance of the atmosphere). Connected across the battery is a perfect voltmeter, i.e. it consumes no current. It is also possible to connect a resistor R across the battery by means of switch S1.

With the switch in the off position the voltmeter will show the voltage of the battery as E volts. If the switch is now closed the voltage shown by the meter will fall due to the current flowing through R_B and R in series. Call this voltage V.

As the same current flows through both resistors their resistance will be proportional to the voltage across them. V is the voltage across R and the voltage across R_B is E – V. This gives:

$$R_B / R = (E - V) / V$$

Multiplying by R we get:

$$R_B = ((E - V) / V) \times R$$

and perhaps a more convenient form:

$$R_B = ((E / V) - 1) \times R$$

and finally:

$$R_B = (E \times R / V) - R$$

FIELD EFFECT

Although primarily intended for the observation of atmospheric electricity, the meter described here is very sensitive, quite easily constructed and doubtless adaptable to other fields of interest, including pollution.

Out of curiosity, the author set up the arrangement of Fig.1 in his lounge. The meter reading was zero until the TV was switched on, it then fluctuated rapidly and seemed to be related to the picture make-up!

Whilst Fig.1 allows the device to be used to determine the potential at a given height as well as a figure for the effective resistance of the air at that height, Fig.3 shows a method of obtaining a figure for the resistance of the air by direct measurement. It has been suggested that the resistance of the air and the amount of air pollution are inversely related.

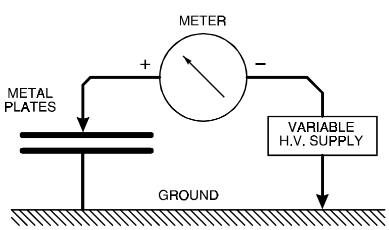


Fig.3. Principle for measuring the resistance of the air.

In Fig.3 the metal plate of Fig.1 is replaced by a pair of metal plates 140mm square and separated by 20mm. The separation can be achieved using two pieces of plastic tube. Make shallow slits 20mm apart in the side of the tubes with a saw and then push two opposite corners of the plates into the slits (see photo below).

The plates are supported one meter above ground and the lower plate is connected to ground. The high voltage supply can then be set to any voltage up to 300V and the meter will again indicate the voltage across its resistance and we end up with arithmetic similar to that used before. In this case the resistance (R_p) between the plates will be equal to:

((high voltage setting – meter reading) / meter reading) x meter resistance

TEST RESULTS

The author's results so far obtained by using the Fig.1 system are as follows:

Taken at a height of 0·5 meters from 1 Nov '99 to 19 Dec '99, from 41 readings the average voltage was 83·3V and the average resistance 10·1 tera ohms (one tera ohm = one million million ohms). The plate is one tenth of a square meter, so the figure for one square meter will be 1·01 tera ohms.

Taken at a height of one meter from 4 Jan '00 to 21 Feb '00, from 22 readings the average voltage was 69·2V and the average resistance 8·14 tera ohms, or 0·81 tera ohms per square meter.

All readings were taken under a blue sky with little breeze during the hours of daylight.

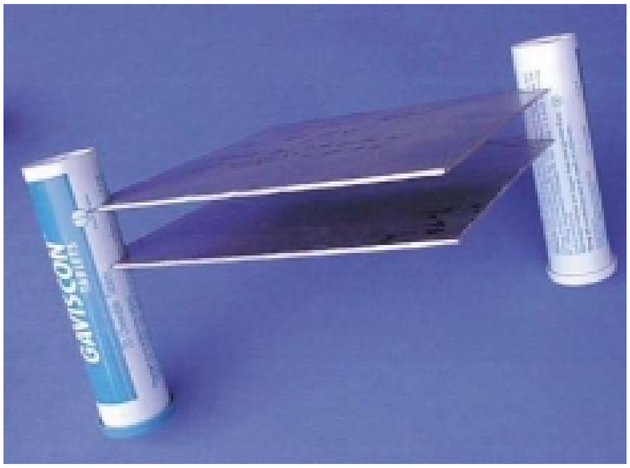
Using the two plates of Fig.3 a reading under calm but overcast conditions at a height of one meter gave a reading of 2·4V with 100V applied, giving an R_p value of 4·06 tera ohms. Corrected to a one meter cube gives 4 tera ohms. The correction on the two plates is 0·98.

It is not clear what the relationship is between the two possible resistance values, if indeed there is one! There are lots of other questions to be answered, for example the value given for E at a height of 0·5m was greater than the one obtained for 1m.

This is contrary to expectations, it would seem reasonable to expect a more or less linear increase in E with height, and ideally this could be solved by simultaneous measurement at several heights. The difficulty here is that the values change quickly so the author is waiting for a nice calm day when conditions are stable before drawing further conclusions.

EXPERIMENTAL ASSEMBLY

The equipment needed to perform such measurements is fairly simple to construct, there being only one or two spots where special arrangements are required, mostly concerned with maintaining the required insulation resistance. It can be split into six parts:



Practical plate construction for use with the test schematic in Fig.3.

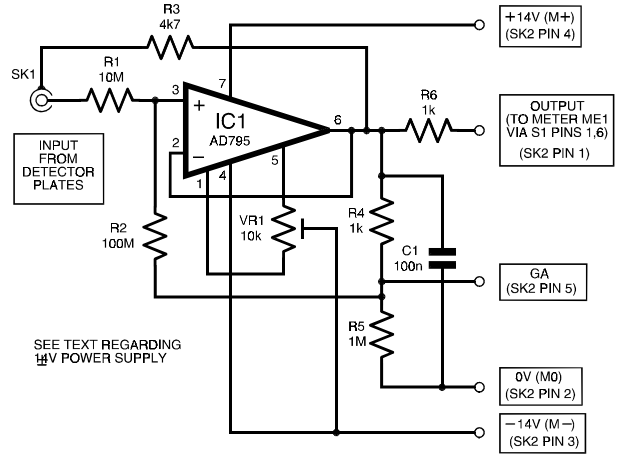


Fig.4. Circuit diagram for the meter interface buffer.

- o) High resistance meter interface
- o) Variable high voltage supply
- o) System metering
- o) System interconnections
- o) Probes (plates)
- o) Construction

Note that the 300V variable voltage supply also incorporates an isolated ±14V supply for the meter. This is necessary because, as Fig.1 shows, there can be a high voltage present between the meter and ground. This high voltage supply is inherently safe because it is designed with a very limited current capability.

METER CIRCUIT

The schematic in Fig.4 shows the basic circuit diagram for the meter interface buffer. (The meters will be discussed next month.) When the input is connected via socket SK1 to a suitable antenna or probe (e.g. the metal plate mentioned with regard to Fig.1 and Fig.3), this circuit allows atmospheric electricity to be monitored via a suitable meter connected to its output. It is quite simple to construct although there are one or two peculiarities.

First note that the use of an AD795 for opamp IC1 is not essential but if an alternative is sought its input bias current must be very small because it is passing through a 100MΩ resistor (R2). The AD795 bias current is less than 1pA and the offset voltage less than 250uV. The input resistance of this design is 100,000,000,000 ohms, perhaps better described as 10^{11} ohms or 100 gigohms (GΩ).

The circuit is basically a voltage follower hiding behind one or two minor modifications. It requires a power supply of between ±12V and ±15V.

Resistor R1, in series with the input to the opamp (pin 3), is a protection resistor. This meter interface is intended to be mixed up with static and various other unpleasant things, at least unpleasant as far as semiconductors are concerned. As a consequence, R1 is intended to reduce the possibility of damage to IC1. Although R1 is 10MΩ, this value is of no consequence to the normal operation because of the effective input resistance of IC1.

Next, one would expect the input bias resistor (R2) to be connected to the 0V line. Instead, connecting it to the junction of resistors R4 and R5 effectively multiplies its value by 1000. This is how the massive input resistance is achieved. R2 is already large, 100MΩ, multiplying it by 1000 gives the required figure. This arrangement is known as bootstrapping, although the term is also applied to other similar techniques. How this works is most easily seen by going through an example:

Suppose the input at pin 3 is 1V, the output at pin 6 will also be 1V. The ratio of R4 to R5 is one to a thousand so that the voltage across R4 will be 0·99mV. Let's call it 1mV as a close approximation. Under this the voltage across R2 will be 1mV and the current through it equals 1mV / 100MΩ (I = V / R), that is 10^{-3} / 10^{-8} or 10^{-11} amps. However, the voltage at pin 3 is 1V and the current taken is 10^{-11} amps. The effective resistance must therefore be 1 / 10^{-11}, which is 10^{11} ohms.

The next point to be made is about resistor R3. This provides what is known as the guard connection. As it is necessary to use an input cable that is

The author's prototype single-plate atmospheric detection platform.

screened to connect the meter interface, the screen is connected to R3. There is thus no voltage difference between screen and the conductor, so that leakage is minimized.

Lastly, capacitor C1 stabilizes the opamp to prevent the possibility of high frequency oscillation and also serves to prevent interference gaining access via either the input or output connection.

Note that the connection labeled GA is not used.

DUAL VOLTAGE POWER SUPPLY

Harking back to Fig.1 for a moment, the meter will be operating at some considerable potential above ground because, whilst the open circuit voltage on the plate E is being measured, both the input and the 0V line of Fig.4 will be at the same potential. This means that the dual power supply for the meter interface must be isolated from ground and this supply is generated in a common unit along with the high voltage supply.

In fact there are limits on the power supply. A lower limit of ±12.5V is set by the opamp type in the meter interface circuit (IC1 in Fig.4) which must provide an output from –10V to +10V. Usually there is a requirement for an allowance (known as headroom) of about 2·5V between the supply and the maximum output voltage.

An upper limit is set by the opamp manufacturer and is very often ±15V with an absolute maximum of ±18V.

Consequently, the value chosen for the prototype is ±14V, which makes allowance for both requirements. This supply is generated using a separate circuit to be described in a moment.

A continuously variable high voltage supply from 0V to at least 300V of either polarity must also be generated. This supply must be inherently safe, or at least the user must be! This is achieved by arranging that the high voltage supply has a high internal resistance so that the output current is very limited. This supply must also be isolated from ground so that it can be switched to either polarity.

There is also the question of what primary power source is to be used and a 12V battery was chosen. This makes the equipment portable and also safe from mains failure. As in the author's set-up the battery is simultaneously charged from the mains, it was preferable that a voltage of between 11·5V and 13·8V should be allowed for the primary source. This is all achieved as shown in Fig.5.

POWER SUPPLY GENERATOR

In this circuit IC2 is configured as an oscillator whose output is coupled to two transformer and rectifier circuits. The first, based around transformer T1, generates ±14V. The second, based around T2, is a variable generator which can be set for any voltage between 0V and 300V, approximately.

Op.amp IC2 is in fact an audio power amplifier. However, it will also operate as a power oscillator and this is how it is used here. Capacitor C2 determines the frequency, in this case about 50kHz. Diode D1, resistor R8 and capacitor C3 are bootstrap components for pin 7 so that the IC can achieve a voltage output close to the supply rails.

Output pin 5 drives the primaries of the two transformers T1 and T2, via capacitors C4 and C5 respectively. The output of T1 is rectified by diodes D2 and D3, smoothed by capacitors C6 and C7, and regulated at ±14V by the Zener diodes D7 and D8.

The output of T2 is applied to a voltage doubling circuit, comprising D4, D5, C8 and C9. The drive to its primary is controlled by TR1 and D6, the affect of which depends on the base current produced by the DC voltage applied to R11 from the high voltage adjustment control input.

Note that capacitors C8 and C9 must be rated at 250 volts working and therefore all the

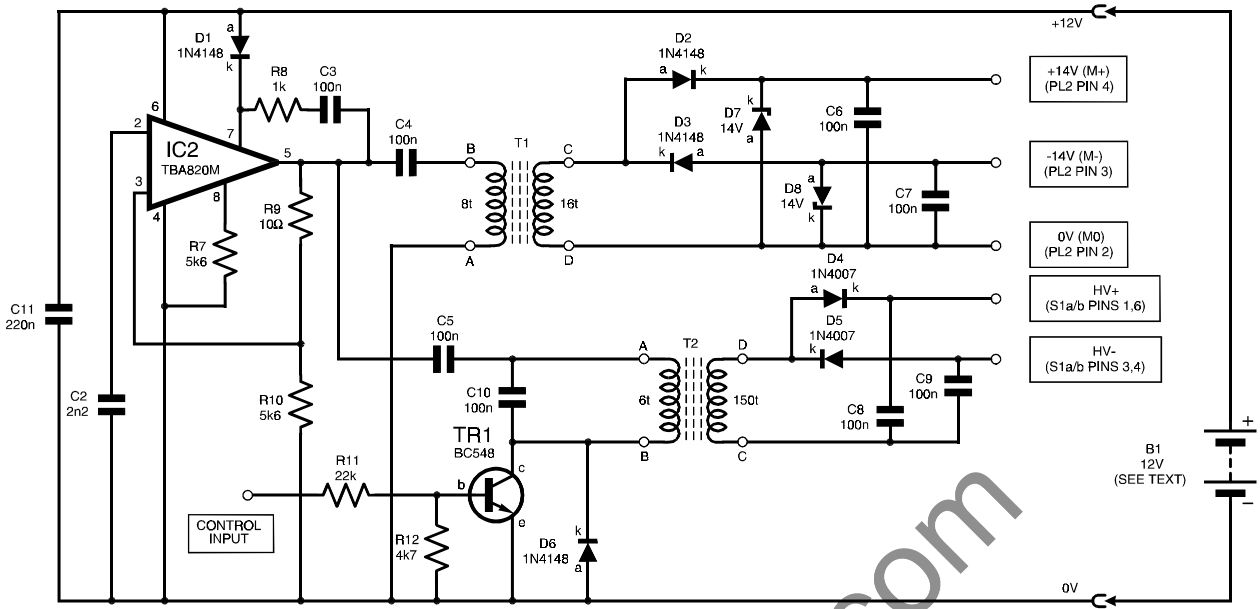


Fig.5. Dual voltage power supply generation circuit diagram plus variable 300V supply.

100nF capacitors have been specified at the same rating.

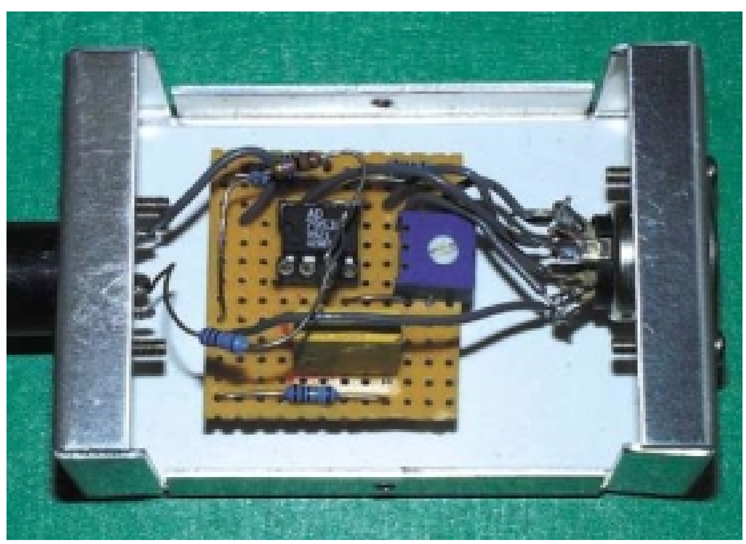
METER INTERFACE CONSTRUCTION

The meter interface circuit can be built using stripboard and a layout is suggested in Fig.6. It is prudent to use a socket for IC1 so that it can easily be replaced if it does have a mishap. Always ensure that IC1 is correctly orientated.

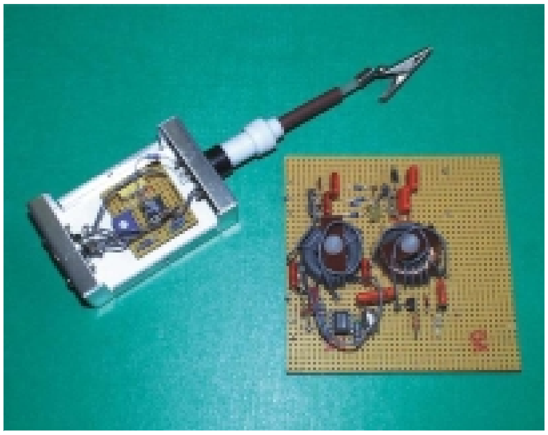
The most important part of the construction to be noted is that pin 3 of IC1 must be bent out sideways so that when the IC is fitted pin 3 is well away from the board. The two resistors R1 and R2 are soldered directly to pin 3 and supported on their wires and should not touch anything!

During the setting up operation the input must be entirely screened. This is most easily done by mutilating a standard cable mounting coaxial plug. To do this unscrew the cap and remove the central conductor and the cable clamp. Then bung up the cap with a scrap of aluminum foil crushed into a ball. This should be a firm fit in the cap. Replace the cap on the body of the plug and the job is done.

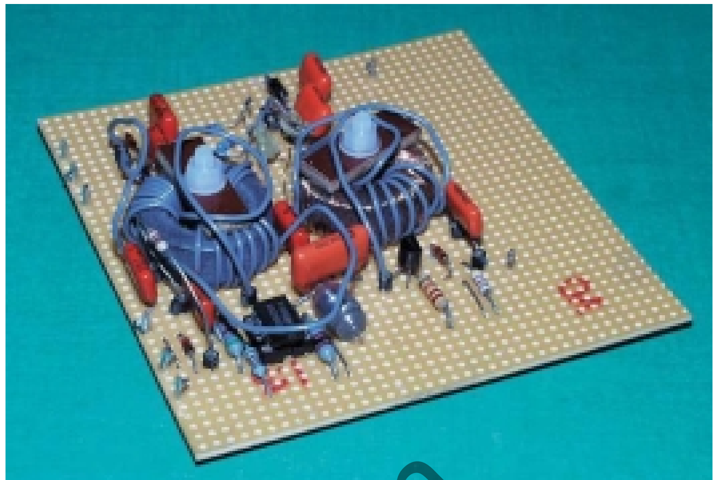
Connector SK2 is a 7-pin DIN socket and SK1 is a TV aerial socket. The latter is special in that both center connector and the screen connector must be insulated from the aluminum case. There are some connectors which are in a plastic molding and one of these will be fine. If this type is not available then the more normal socket with the metal outer can be used but it will have to be insulated from the case by mounting it on a piece of insulating board.



The meter interface board mounted in its case. A piece of card is placed between the board and bottom of case to prevent any "short circuits".



Meter interface unit complete with crocodile clipped connection link, plus the constructed power supply board.



Close up details of the constructed power supply board.

An aluminum case needs to be used, measuring about 76mm x 50mm x 25mm. The DIN socket should be fitted at one end and the TV coaxial socket at the other.

POWER SUPPLY CONSTRUCION

The secondary winding on the high voltage transformer T2 is 150 turns of 36 gauge (0·2mm) enameled wire. For those who haven't played this game before, use a shuttle. This can be made from a piece of card or plastic that will pass through the center of the toroid and which has a slot at either end so that the wire can be wrapped round the shuttle lengthwise.

It is as well to first put 10 turns on the toroid the hard way, take it off and measure it so that the required length for 150 turns can be worked out. Allow plenty for the ends. The wire is much cheaper than patience!

The primary for transformer T2 has only six turns. For T1, the primary has eight turns and the secondary 16 turns. As the other windings have only a few

COMPONENTS

Resistors
- R1 10M
- R2 100M high ohmic cermet film
- R3 4k7
- R4, R6 1k (2 off)
- R5 1M
- R7 5k6 1% metal film
- R8 1k 1% metal film
- R9 10k 1% metal film
- R10 5k6 1% metal film
- R11 22k 1% metal film
- R12 4k7 1% metal film
- R13 100k
- R14 22k
- R15 3M

All 0.25W 5% carbon film or better unless otherwise indicated

Potentiometers
- VR1 10k miniature preset, square
- VR2 50k miniature preset, round
- VR3 10k carbon rotary

Capacitors
- C1 100n polyester, 12.5mm spacing
- C2 2n2 polystyrene
- C3 to C10 100n polyester, 250V (8 off)
- C11 220n polyester, 250V

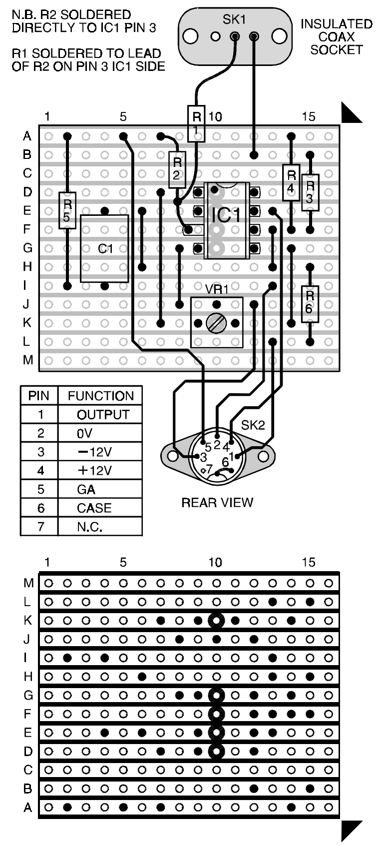
Semiconductors
- D1 to D3, D6 1N4148 signal diode (4 off)
- D4, D5 1N4007 rectifier diode (2 off)
- D7, D8 14V 400mW Zener diode (2 off)
- TR1 BC548 *npn* transistor
- IC1 AD795 opamp
- IC2 TBA820M power opamp

See also the SHOP TALK Page!

Miscellaneous
- B1 12V battery (see text)
- B2 AA cell (2 off)
- SK1 coax socket, insulating (chassis mounting) (see text)
- SK2 7-pin DIN socket (chassis mounting)
- S1 d.p.d.t. miniature toggle switch
- S2 s.p.s.t. miniature toggle switch
- S3 d.p.d.t. toggle switch, 240V AC rated
- S4 s.p.d.t. toggle switch, 240V AC rated
- PL1 coax plug (cable mounting)
- PL2 7-pin DIN plug (cable mounting)
- ME1, ME2 panel meter, 0.1mA full scale deflection (2 off)
- T1, T2 ferrite toroid B64290K618X830 (25mm diameter) (2 off)

Stripboard, 0.1-inch, 39 strips x 39 holes; stripboard, 0.1-inch, 12 strips x 13 holes; metal case 75mm x 50mm x 25mm; metal case to suit power supply control unit (see text); knob for VR3; 8-pin DIL socket; crocodile clip; 36 gauge (0.2mm) enameled wire (see text); nylon nut and bolt to suit (see text) (2 off each); aluminum plate 316mm x 316mm x 2mm (or thicker); support hardware (see text); 6-way cable

Approx. Cost Guidance Only *(Excluding batteries, meters, cases, and hardware)* **$30**



PIN	FUNCTION
1	OUTPUT
2	0V
3	−12V
4	+12V
5	GA
6	CASE
7	N.C.

Fig.6. Meter interface stripboard component layout, details of breaks required in underside copper tracks and wiring to off-board components.

turns, so the wire can be threaded through. Plastic covered connection wire will do, e.g. 1/0·6.

Assembly details for the power supply board are shown in Fig.7. There is nothing special about the layout so it can be varied to suit different component sizes. Be careful with the cuts in the tracks since these must be done on the reverse side. It is easiest to poke something through from the front to help mark a cut position.

The two transformers should be fastened to the board, ideally using a nylon nut and bolt, passing the bolt through a piece of plastic, through the center of the toroid and through a hole in the matrix board. Tighten the nuts just sufficiently to hold the toroids in place.

NEXT MONTH

In the final part next month we conclude the construction and describe the metering and monitoring probes.

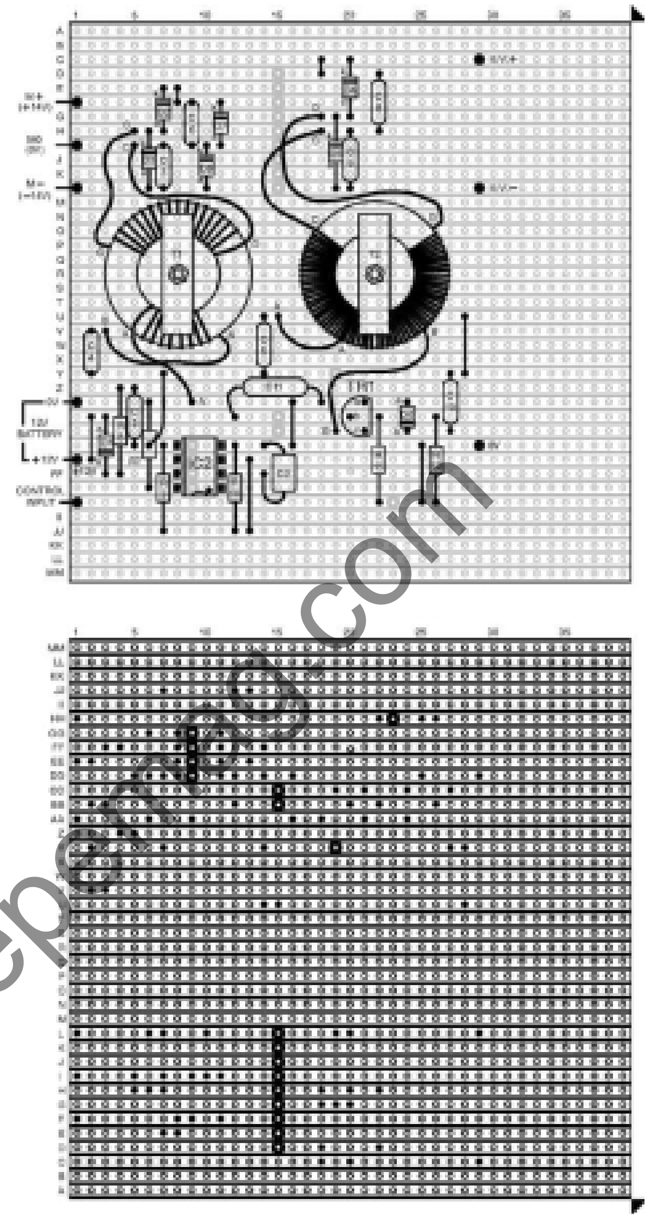


Fig.7. Power Supply stripboard, topside component layout and underside copper track break details. Note that the two toroid transformers are bolted to the board using nylon nuts and bolts and two strips of plastic