Project 158

Test meter measures resistance from 100 ohms down to 0.005 ohms

At some time or another, every practical electronics hobbyist will need to measure a low-value resistance that the ordinary multimeter can't cope with. This project, which has applications in many situations, solves this problem.

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Development: **Simon Campbell**

THERE COMES a time in the life of every person involved in electronics in a practical way when the need to measure a resistance outside the range of common multimeters arises. What do you do? Some squint at the scale of their analogue multimeter and guess that the needle, close as it is to the end of the scale, is somewhere in 'the ballpark'. Others stare at the LCD display of their digital multimeter and despair as it reads "00.2 ... woops, 00.3 ... um, 00.2" etc. At this stage you can resort to a power supply to drive some current through the resistance to be measured and use your multimeter to measure the voltage drop across it. If you can read 1 V on your multimeter with sensible accuracy you'll need to drive two amps through a half ohm resistance. And that's not a good idea for a transformer winding rated at 200 mA, for example.

This project solves the difficulties generally experienced when you try to measure low value resistances. It has applications in many situations. When paralleling power transistors or three-terminal voltage regulators, for example, 'ballast' resistors are required so that each device in the circuit shares the load current equitably. These ballast resistors generally have values much less than one ohm, sometimes less than one-tenth of an ohm (0.1 ohm or 0R1). You can make a rough estimate of the length of copper wire of a particular gauge necessary to make a resistance of the desired value, simply from the published ohms/metre data on the wire gauge, but several pieces of wire cut to the same length from the same reel will not be the same resistance, and the actual resistance may be 20% or more different from the value required, owing to variations in the composition of the wire, diameter, etc. With our Low Ohms Meter, you can cut them to the value required and be assured of the result.

Other applications are: measuring the resistance of transformer windings, measuring the resistance of cable joints, measuring the resistance of tracks on printed circuit boards, etc.

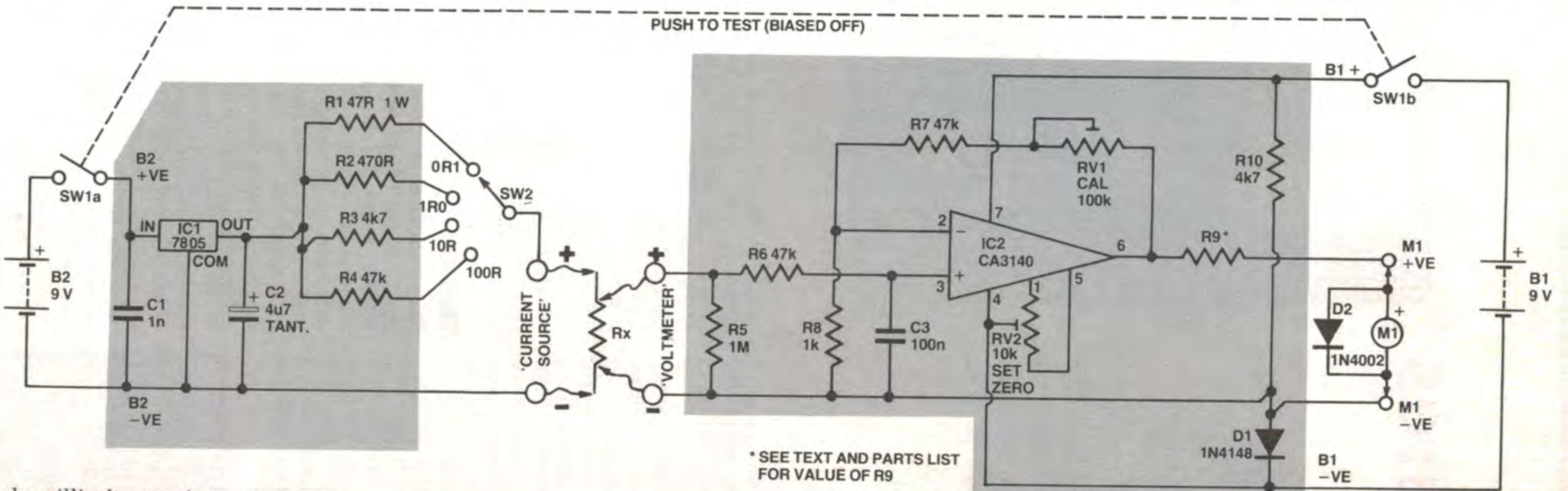
Design

The instrument consists of a multi-range current source and a dc millivoltmeter. The measuring method is known as a 'four-terminal' technique and it has the advantage of eliminating the effect of the leads connecting the instrument to the resistance to be measured. The current source provides a predetermined constant current that is 'driven' through the resistance to be measured. The voltage drop across the unknown resistance is then measured with a high input impedance dc millivoltmeter. The meter reading is directly proportional to the resistance being measured. This gives a linear scale, which is an advantage. The maximum current supplied by the current source is about 100 mA (only on the 0R1 range), which is quite safe in the majority of circumstances encountered. ▶

SPECIFICATIONS — ETI 158

Ranges (full-scale):	100R,10R,1R0,0R1
Resolution:	0.05 of full-scale reading (0.005 ohms on 0R1 range)
Accuracy:	2.5% of full-scale reading or better (depends on meter used)
Maximum test current:	100 mA (approx.) (0R1 range)
Minimum test current:	100 uA (approx.) (100R range)

Project 158 — low ohms meter



* SEE TEXT AND PARTS LIST FOR VALUE OF R9

The dc millivoltmeter has a full-scale sensitivity of 10 mV. The current source provides a current on each range such that 10 mV is developed across an unknown resistance of the maximum value in each range. This four-terminal technique is widely used in precision measurement applications.

How does the instrument ignore the effect of the resistance of the connecting leads? Well, let us examine the worst case — say we are attempting to measure a resistance of around one-tenth ohm. The range switch (SW2) will be switched to '0R1'. This selects R1 to limit the maximum current to be supplied from the voltage regulator IC1, which provides 5 V. Now, if each lead from current source terminals to R_x has a resistance of half an ohm, a total resistance of one ohm will be connected in series with R_x. If R_x is one-tenth of an ohm (0.1 ohm or 0R1), then the total resistance placed across the current source terminals will be 1.1 ohms. As this is in series with R1, the current now flowing through R1, the leads and R_x will be given by:

HOW IT WORKS — ETI 158

The unit contains two separate circuits — a constant current source and a dc millivoltmeter. The constant current source drives a suitable current through the unknown resistance (R_x). The current can be selected by means of a switch (SW2, the 'range' switch). The consequent voltage drop across the unknown resistance can then be measured with the dc millivoltmeter. As the resistance of R_x is directly proportional to the voltage drop across it, and the current driven through it is known to be a constant, the meter scale may be calibrated directly in ohms (or fractions of an ohm).

The constant current source is quite simple and comprises B2 (9 V), IC1, R1 to R4, SW2 and associated components to the left of R_x in the circuit diagram. IC1 is a 7805 three-terminal, 5 V positive regulator. Capacitors C1 and C2 provide high frequency stability. Resistors R1 to R4, selected by SW2, set the current that flows in the unknown resistance, R_x. When the '0R1' range is selected, the current (limited by R1) will be around 100 mA. When the '1R0' range is selected, R2 will limit the current to around 10 mA ... and so on, through the ranges. Now, on each range, the value of the unknown resistance, R_x, will be very much lower than the value of the current limiting resistor (R1, R2 ... etc), by a ratio of around 500 to 1. The voltage drop across R_x will also be much, much lower than the output of IC1. Consequently, the test current from the current source is virtually independent of both lead resistance and the unknown resistance. On the '0R1' range, a total lead resistance of one ohm between the 'current source' terminals and the resistance being measured will only introduce an error of 2%. On the '100R' range, the same lead resistance will introduce an error of only 0.002%. The accuracy of the instrument is primarily determined by the tolerances of R1 to R4 and the meter accuracy.

The dc millivoltmeter is based on a CA3140 FET input op-amp. This IC has the advantage that it will respond accurately to dc inputs right down to 0 V. The voltmeter terminals are connected to the unknown resistance so that the meter circuit can indicate the voltage drop across the unknown resistance produced by the current source. The voltmeter circuit has a very high input impedance so that the current flowing into the voltmeter input resistance is very much less than the current flowing through R_x. The voltmeter input impedance is principally determined by R5, a 1M resistor. IC2 amplifies the voltage drop across R_x, its output driving a meter. The gain of IC2 is proportional to the ratio of RV1 plus R7 to R8 and is set to about 100, so that a voltage drop of 10 mV across R_x will produce an output between pin 6 of IC2 and the 'M1 −VE' terminal of 1 V. Thus, whatever full-scale deflection value meter is used, 1 mA or 100 uA, R9 is selected so that the meter actually reads 1 V full-scale deflection. In fact, M1 and R9 may be dispensed with and you could use a multimeter set to the 1 V scale. Diode D2, mounted across the meter terminals, prevents damage to the meter if the unit is incorrectly ranged so as to produce an output from IC2 of greater than 1 V. Being a silicon diode it will conduct when the voltage across the meter terminals rises to about 0.6 V.

So that any dc offset in IC2 can be compensated for, a zero set adjustment is provided. In order to set this accurately, the output of IC2 needs to be driven slightly negative and a small negative potential is developed across a forward-biased diode, D1. Current through R10 biases this diode on.

To accurately set the full-scale reading of the dc millivoltmeter, the gain of IC2 is adjusted by RV1 with a known accurate resistance placed in circuit.

Capacitor C3 bypasses hum and noise at the input of IC2, picked up by the leads from the 'voltmeter' terminals connecting to R_x.

As B2 has to supply up to 100 mA of current, a large-capacity battery is suggested. The dc millivoltmeter circuit only draws a few milliamps and thus a standard 9 V transistor radio battery is all that is required.

$$\frac{5}{47 + 1 + 0.1} = \frac{5}{48.1}$$
$$= 104\ \text{mA}$$

Now, if the lead resistance were zero, the current flowing through R_x will be given by:

$$\frac{5}{47 + 0.1} = 106\ \text{mA}$$

Thus a lead resistance of one ohm between the current source terminals and the resistance being measured will introduce a percentage error of:

$$(\frac{106}{104} \times 100) - 100 = 1.9\%$$

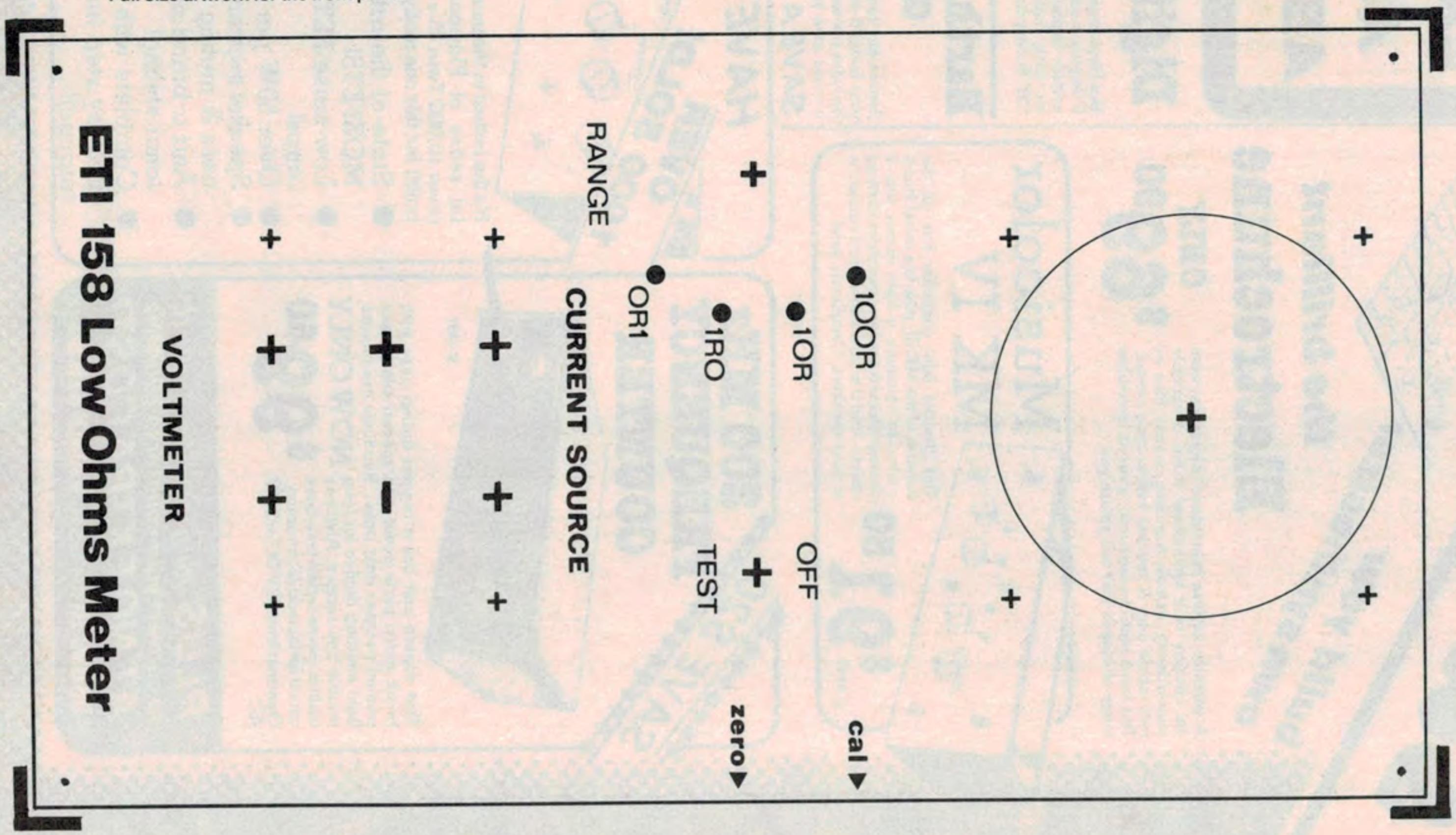
Looking at it another way, the ratio of the current-limiting resistor selected by the range switch (R1, R2 ... etc) to the resistance of the connecting leads between the current source terminals and R_x is very high, and thus it is the current-limiting resistor which principally determines the current driven through R_x.

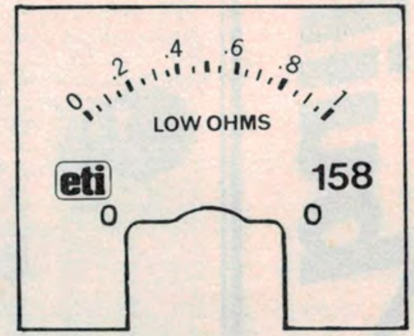
The dc millivoltmeter connects across the resistance being measured. It has an input impedance principally determined by R5, as IC2 is a CA3140 FET input op-amp with an input impedance specified as 1.5 Teraohms (10^{12} ohms!) In the worst case, when using the 100R current source range and measuring a 100 ohm resistor, the dc millivoltmeter input impedance will be 10 000 times larger than R_x and its effect will thus be insignificant. As the dc millivoltmeter is connected directly across the unknown resistance, and not across the current source terminals, the voltage drop across the leads from the current source terminals to the unknown resistance is ignored.

In practice, the accuracy of the instrument will be determined by the accuracy of the meter movement used. Most common, low-cost meter movements are 'Class 2.5' types with an accuracy of 2.5% of full-scale reading.

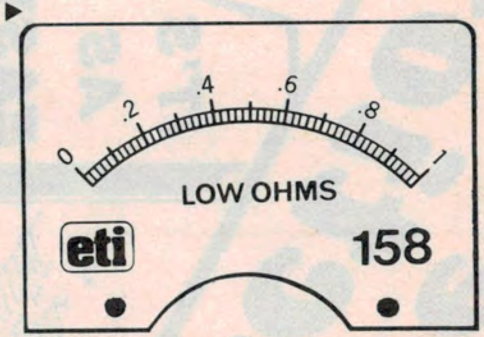
A variety of meters may be used. The common 1 mA movements are inexpensive and there are several models around. Alternatively, 500 uA or even ▶

Full size artwork for the front panel.

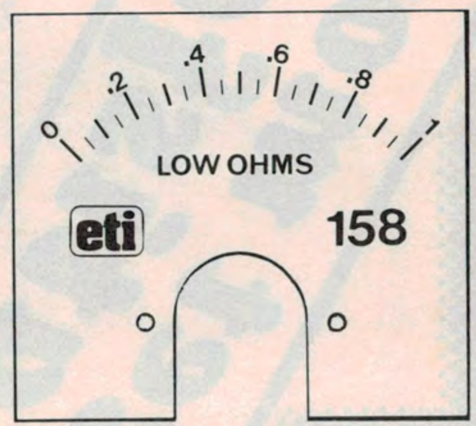




Scale for the Minipa MU-45.



Scale for the SEW ST-65



Scale for the University TD66

100 uA movements may be used. However, you'll find that different makes in the same sensitivity have different impedances. We used a University TD-66. These have a 100 ohm impedance in the 1 mA movement and a 2k impedance in the 100 uA movement. The Minipa meters in the MU-45 size have a 120 ohm impedance for the 1 mA movement, 1400 ohms for the 50 uA movement. The value of R9 needs to be chosen to suit the sensitivity of the meter movement used. The CAL adjustment takes care of the different meter impedances as the gain of IC2 is set to suit.

For a 1 mA movement with an impedance between 100 and about 300 ohms, R9 should be 820R 1% or 2%. For a 50 or 100 uA movement with an impedance of between 1k and about 3k, R9 should be 8k2 1% or 2%.

Construction

The electronics are contained on a small 50 x 100 mm printed circuit board and the major components are mounted on the front panel of a conveniently sized jiffy box. While we have chosen to mount the electronics on a printed circuit board, layout is not critical and they may be mounted on matrix board, Veroboard, Uniboard or whatever.

If you elect to build your unit in the same fashion as we did our prototype, then the best place to start is with the mechanical work. We dressed up our front panel with a Scotchcal overlay, the design of which is reproduced on page 57. You can use this to mark out the drill hole positions on the jiffy box front panel. Note that the holes for the meter are marked out for a University model TD-66 meter movement. You will have to mark out holes to suit the meter you have if you intend using another type. Centre punch the holes to be drilled and then drill them carefully. Sizes will vary depending on the particular components used so we haven't given any hole dimensions. Note that for the voltmeter and current source terminals we used spring-loaded speaker terminals which are conveniently colour-coded black (−ve) and red (+ve). We drilled holes behind the terminals where the solder connection to each protrudes through the panel — no need to cut slots.

Cutting the meter hole can be a hassle if you don't have a hole cutter. There are several ways to do it. One is to mark a circle on the panel just larger than the diameter of the hole required. Then, using a 3 mm or 4 mm diameter drill bit, cut a series of holes around this ring — each hole overlapping the last. The centre piece may then be pushed out and the edge of the hole cleaned up with a fine-cut half-moon file. Tedious, but it works. Another method again requires marking a hole just larger than that required and then drilling a large hole inside the circle, inserting a 'nibbling' tool and then cutting around the marked circle.

Having drilled the front panel, do a trial 'fit' of all the components that mount on it just to see that nothing needs to be adjusted or holes reamed out, etc.

If all is well, you can take the parts off the panel and then carefully stick the Scotchcal label to the panel and trim the edges. Next mount all the major components in place and orientate SW1 and SW2 so that their operation corresponds to the panel markings.

The pc board assembly may be tackled next. This is quite straightforward and the components may be assembled in any convenient order. Take care though with the orientation of IC1, IC2 and C2. Don't confuse R3 and R10. Note that R3 is a 1% or 2% metal film type whereas R10 is an ordinary 5% carbon type. Likewise, don't confuse R6 with either R4 or R7, as the former is an ordinary 5% carbon type and the latter two are metal film 1% or 2% types. Note that the two trimpots mount with their adjusting screws facing off the end of the pc board. Having completed the pc board, check it and then you can tackle the wiring from the board to the major components on the front panel.

Take care with the wiring to the voltmeter and current source terminals that you get the +ve and −ve connections the right way round. Note that diode D2 mounts on the meter terminals. Also make sure that you wire the meter the right way round. As a variety of switches are available to suit SW2 we have only shown a diagramatic wiring arrangement for this, as the pins may differ between different switch types. The enclosed type, such as those from C&K, have the pole marked 'A' and the switch position marked '1,2,3,4' and they should be wired to conform to the designations on the wiring diagram. The connections to the open type of rotary switch are readily figured out by examination.

Rear view of a C&K four-position switch showing the connections for SW2.

The only other item, or items, to watch concern the battery clip leads — make sure you connect them with the correct polarity.

Having got it all together, check your wiring and you're ready for a test flight. Plug in B1, and with nothing connected to the terminals, operate SW1 ('TEST'). Adjust the 'ZERO SET' trimpot to zero the meter.

Now, obtain a 100 ohm resistor — in fact, it is a good idea to buy a 100R 1% or 2% resistor for calibration use when you buy the rest of the components.

Plug in B2 and connect your resistor to the current source terminals. Take two leads with alligator clips on one end and connect the voltmeter terminals to the resistor — watch the polarity. Set the range switch to 100R and operate SW1. Now, adjust RV1 ('CAL') so that the meter reads full-scale deflection.

Now you're ready to roll, if all is well.

To permit adjustment of the CAL and ZERO trimpots with the project assembled in the case, we drilled two holes in the side of the case to permit access to the trimpot adjustors with a screwdriver. We located the hole positions by temporarily mounting the board in the case and marking the case on the outside where we judged the holes should be. Drill oversize holes and you can't go far wrong!

Assemble the pc board in the case, put the batteries in place and screw on the front panel. Repeat the zero procedure — but first adjust the meter movement mechanical zero, located at the bottom of the meter face. Then calibrate the unit on the 100R range using your 100R calibration resistor. Now you're calibrated and ready for work!

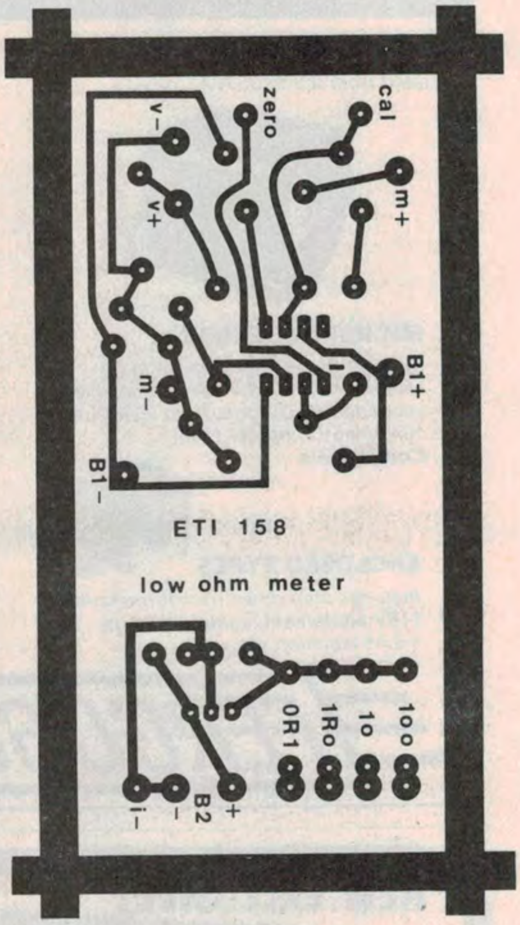
Using it

The 'TEST' switch, SW1, is a spring-return type, so that the measurement current supplied by the current source is only applied for the length of time it takes to make the measurement. This helps to prolong battery life in case you leave the unit turned on and ensures that in applications where the 100 mA maximum test current may cause component heating that it is only applied for a limited period.

In use, always connect the current

source to the unknown resistance with heavy leads that are as short as practicable. The actual connections may well have the greatest resistance, so when using the 0R1 range make sure you arrange good, solid connections to ensure the best accuracy. The voltmeter should be connected with flying leads with clips on the end — always attach the clips across the actual resistance being measured, not across the current source terminals or somewhere on the connecting leads.

To read off resistance, multiply the scale reading on the meter by the setting of the range switch. For example, if the meter reads 0.7 and the range switch is set to 1R0, the value of the resistance being measured is 0.7 ohms, or 0R7. ●



PARTS LIST ETI-158

Resistors

R1	47R/1 W, 1% or 2%
R2	470R/½W, 1% or 2%
R3	4k7/½W, 1% or 2%
R4, R7	47k/½W, 1% or 2%
R5	1M/½W, 5%
R6	47k/½W, 5%
R8	1k/½W, 1% or 2%
R9	820R, ½W, 1% or 2% (see text)
R10	4k7/½W, 5%
RV1	100k cermet multiturn horizontal trimpot
RV2	10k cermet multiturn horizontal trimpot

Capacitors

C1	1n ceramic
C2	4u7/16 V tant.
C3	100n greencap

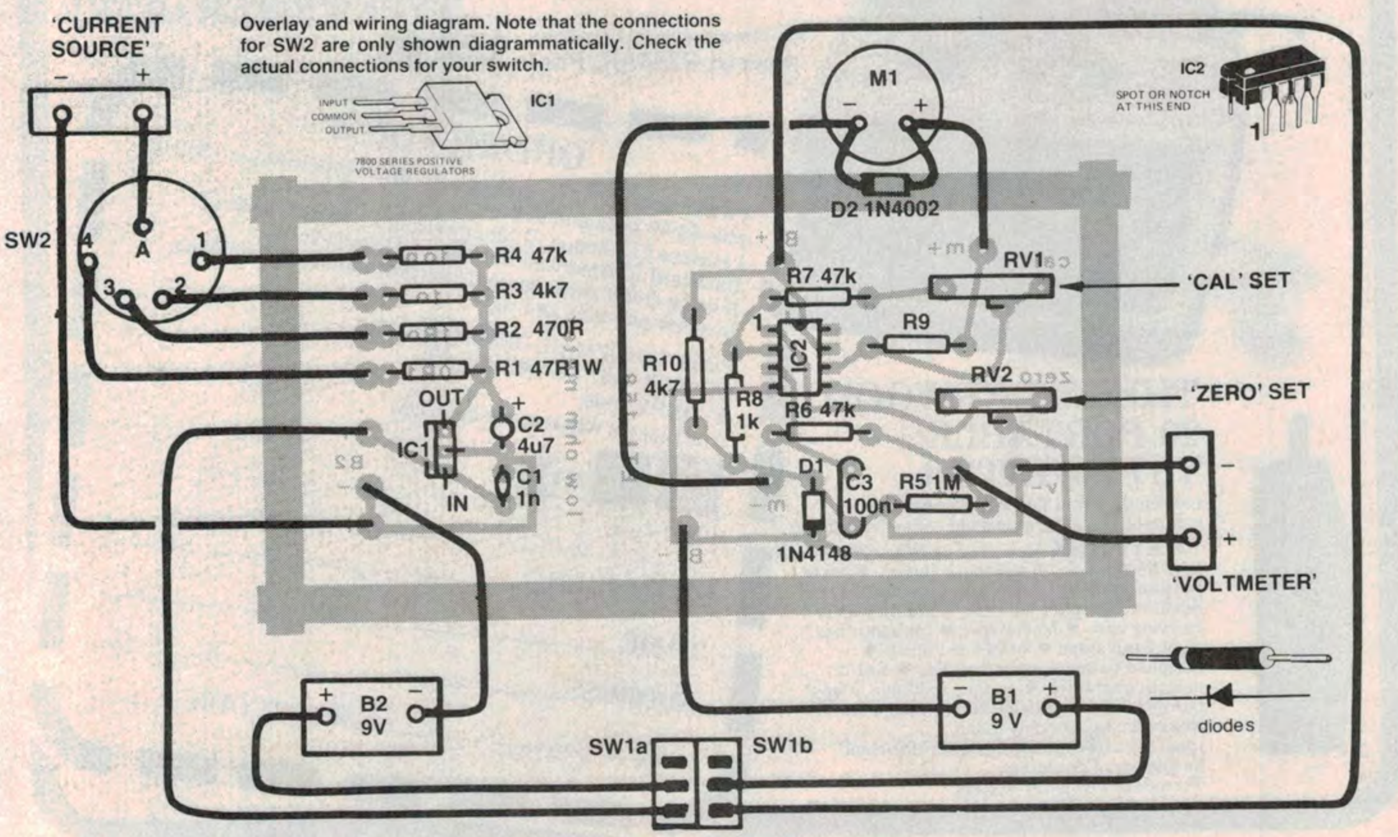
Semiconductors

IC1	7805, LM340/T5 etc, 5 V reg.
IC2	CA3140
D1	1N914, 1N4148 etc.
D2	1N4001, EM401, 1N4002 or sim.

Miscellaneous

SW1	DPST spring-return toggle switch
SW2	single-pole, four-position rotary switch
B1	No.216 9 V battery
B2	No.276P 9 V battery
M1	TD66 meter 0-1 mA, 100 ohms internal resistance (see text)

ETI-158 pc board; zippy box No. H0102 196 x 113 x 60 mm or similar; Scotchcal front panel and meter scale; knobs; spring terminals; battery clips, etc.



Overlay and wiring diagram. Note that the connections for SW2 are only shown diagrammatically. Check the actual connections for your switch.