High impedance AC/DC millivoltmeter

This easy to build instrument will measure AC and DC signals down to a couple of millivolts, with negligible circuit loading.

by ROB EVANS

To successfully measure the voltage levels around most audio circuitry, a meter with quite sensitive ranges and negligible circuit loading is required. The average digital multimeter has a high input impedance, offering minimal loading effects, but rarely has a more sensitive range than 200mV. An equivalent analog style multimeter may have an input impedance of only 4k ohms for a 200mV range, causing serious loading on higher impedance circuits.

The AC/DC millivoltmeter described here is inexpensive to build, has an input impedance of about 7M ohms, and a minimum range of 10mV. This makes it an ideal instrument for testing signal paths and offset voltages in circuitry containing op-amps or transistors. Also, if a standard multimeter is available, this can then be freed to measure other less critical circuit parameters.

In order to maintain a low construction cost, the unit uses an inexpensive meter movement and aluminium box, readily available components, and only one 9V battery. Other features that have been included are battery test and meter zero positions, and a reverse polarity indicator for the DC ranges. The meter scaling and range switch have been calibrated in 10dB steps, to enable relative decibel readings to be made without reaching for the calculator!

Circuit principles

The basis of the circuit appears in Fig.1, as an op-amp with a meter connected in the feedback loop. When a voltage is applied to the non-inverting input, the op-amp output will drive so as to cause the same voltage at the inverting input. Assuming the op-amp input draws negligible current, the meter current may easily be calculated. With the inputs at a potential of 120mV, 1mA will flow through the resistor (120 ohms) and the meter. Consequently, this circuit behaves somewhat like a voltage to current converter. The meter chosen for this design requires 1mA for full scale deflection (FSD), therefore in our simplified circuit an input of 120mV will read as maximum (10) on the scale.

The complete circuit

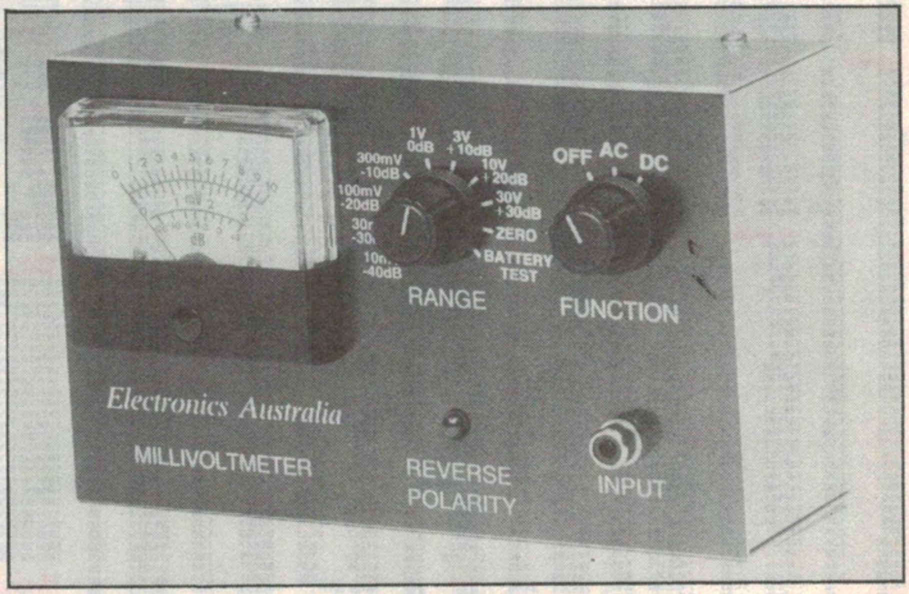
As can be seen in the overall circuit diagram, a diode bridge (D1 to D4) has been added to the output of the meter current driver IC2a. This allows current to flow in only one direction through the meter, regardless of the input voltage polarity. That is, AC signals will be rectified and DC voltages will always cause a forward meter reading, regardless of their polarity. To reduce needle "jitter" at very low frequencies, this rectified signal is filtered by C3.

The diode bridge and meter are included within the negative feedback loop of the op-amp, thereby cancelling any introduced losses or non-linearities, while the maximum available current is limited by R17 so as to avoid meter damage if (or when!) the unit is overloaded.

To achieve the required sensitivity of 10mV, a further stage (IC1) with a gain of 12 has been added. This forms a non-inverting amplifier with the gain set by R15, R12, and RV1 or RV2. This stage will deliver the required 120mV output to drive the following stage, while providing the overall offset adjustment by RV3.

The final gain of the circuit needs to be slightly higher when reading AC voltages due to the meter responding to the average driving current, while calibrated in RMS voltage. The average value of a sine wave is about 10% lower than its RMS value, and this difference is catered for by the selection of a different gain trimpot for each function. Switch 2c selects RV2 for AC measurement and RV1 for DC readings.

To create the eight switched ranges for the millivoltmeter, a resistor voltage divider attenuates the input signal in 10dB steps. The range switch SW1 selects the appropriate "tap" for the range in use, or the common line for the zero set position. The resistors selected for this task are common 5% preferred values, although if higher range accuracy is required, closer tolerance components may be chosen. The sum of this resistor chain is about 7M ohms, therefore the input impedance of the



millivoltmeter will cause negligible loading on the circuit under test.

The last range switch position is a battery test facility, and is enabled in the DC function via SW2b, R11 and R10. The function switch also removes the input isolating capacitor C1 via SW2a when DC is selected, while the remaining section SW2d applies power to the circuit.

The remaining parts of the circuit are the power supply reference and the reverse polarity indication, which simply illuminates a LED if the output of IC2a swings negative with respect to the common line.

To prevent the polarity indicator reacting to AC signals, the output of IC2a is filtered by R18 and C2 when applied to the base of Q1. Therefore, only a continuous negative signal will saturate Q1, and in turn, Q2 via R19. The

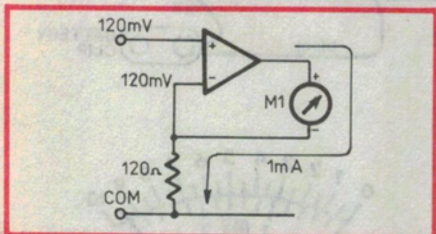
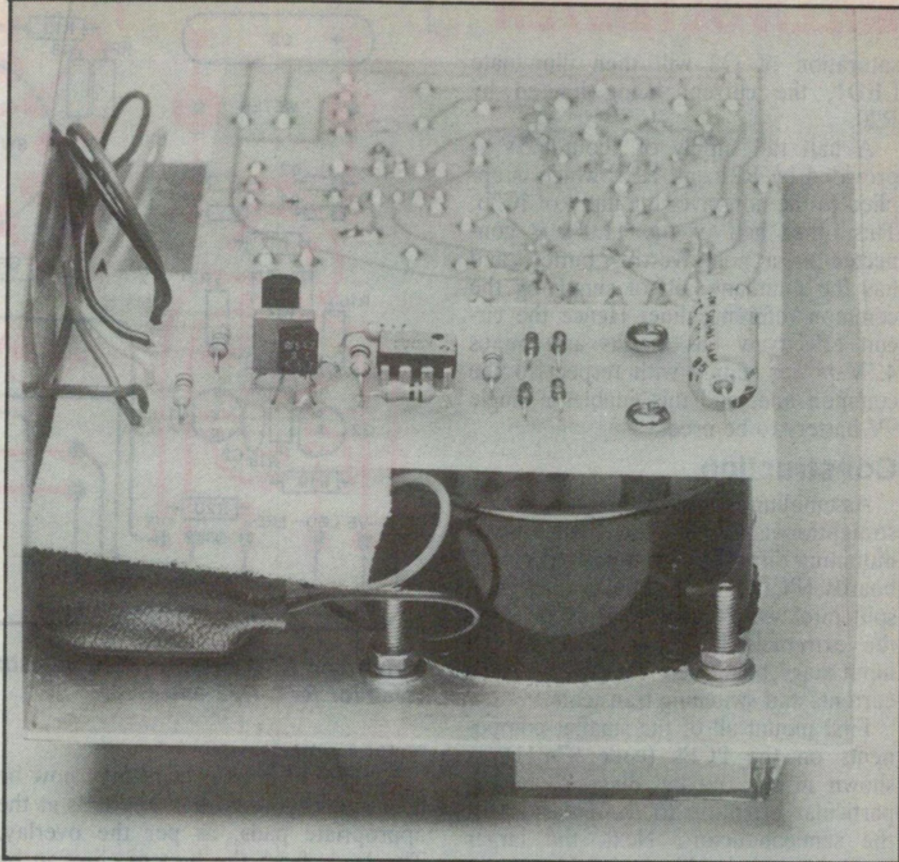
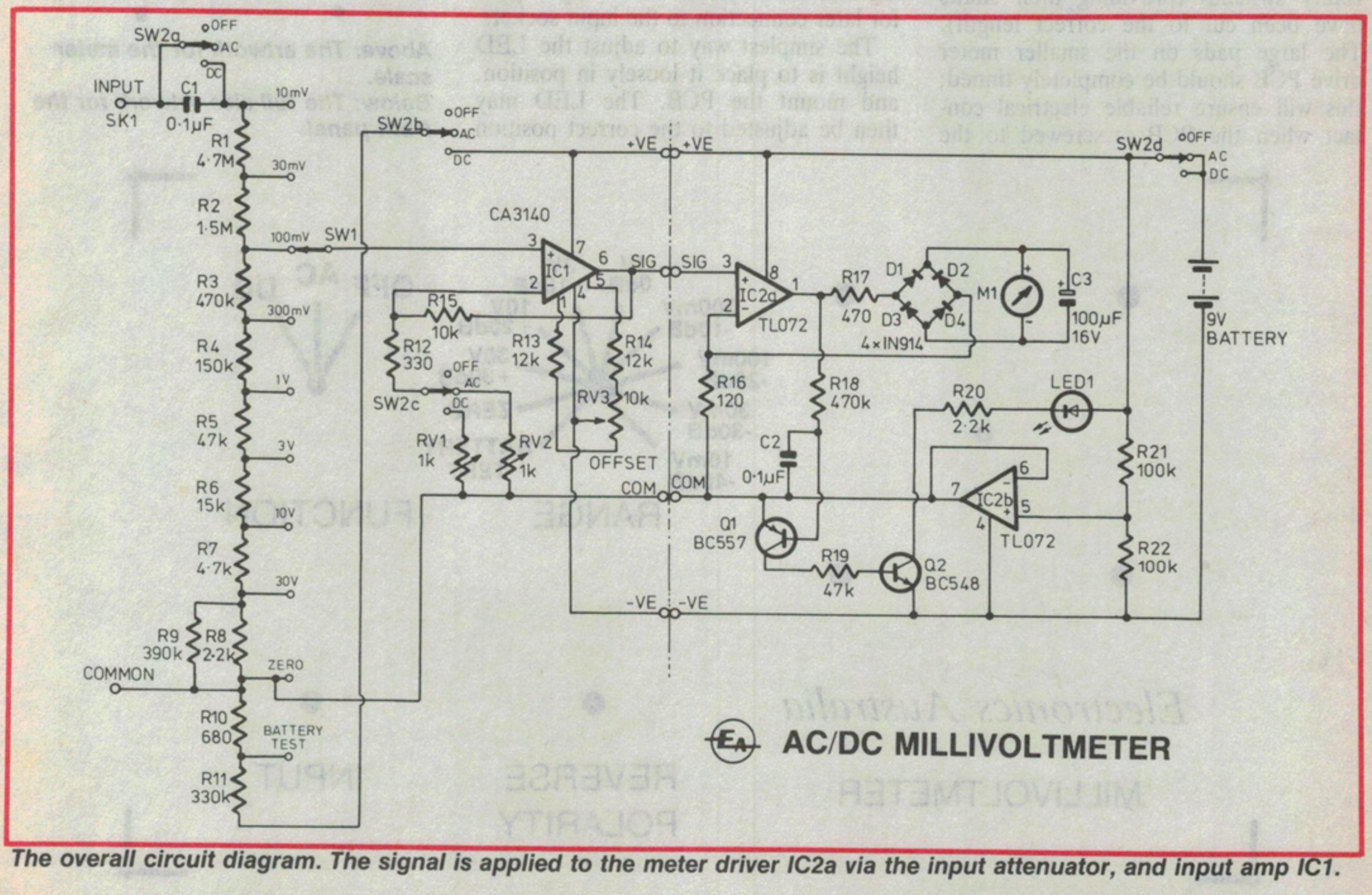


Fig.1: The basic meter drive circuit.



Inside the Millivoltmeter: Note that the meter drive PCB is mounted component side out, while input PCB is copper side out.



The overall circuit diagram. The signal is applied to the meter driver IC2a via the input attenuator, and input amp IC1.

saturation of Q2 will then illuminate LED1, the current being limited by R20.

A half rail supply of about 4.5V is provided by R21 and R22, which is applied to the non-inverting input of IC2b. This other half of the TL072 is connected as a non-inverting buffer, and has the mundane job of supplying the common reference line. Hence the circuit effectively has a plus and minus 4.5V power supply with respect to the common line, and this enables a single 9V battery to be used.

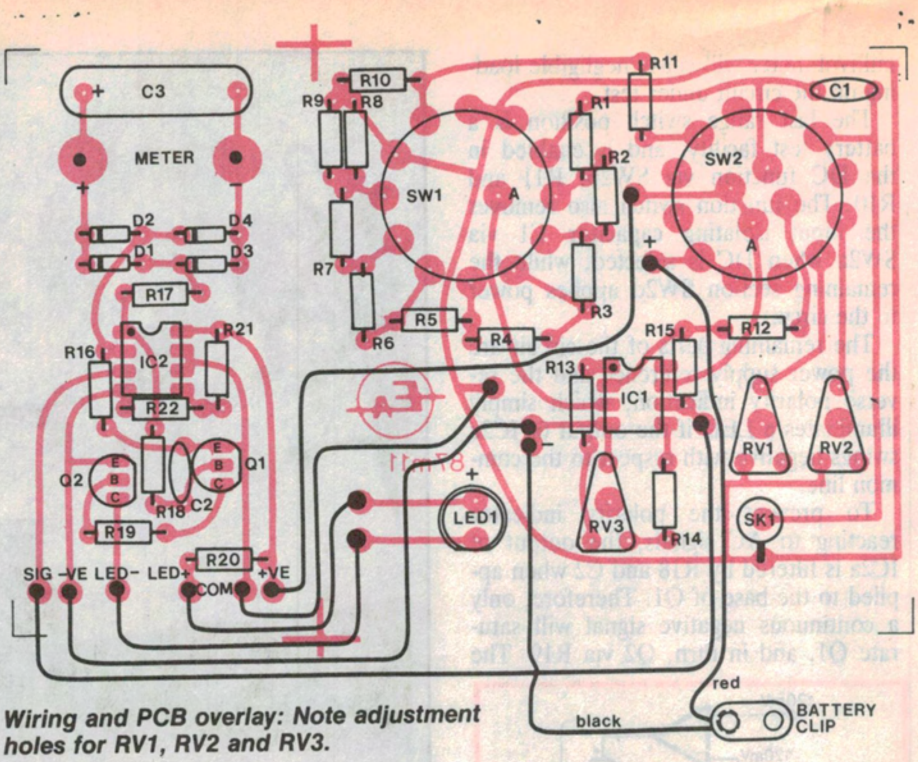
Construction

Assembling the millivoltmeter is quite straightforward, all the components mounting directly on two printed circuit boards (PCBs). The circuitry has been split into two PCBs to ensure stability, the extremely high impedance of the input stage being very sensitive to stray currents and switching transients.

First mount all of the smaller components on the PCBs (code 87m11) as shown in the overlay diagram, paying particular attention to the polarities of the semiconductors. Next, the larger components should be soldered in place, working from the trimpots to the rotary switches (providing their shafts have been cut to the correct length). The large pads on the smaller meter drive PCB should be completely tinned; this will ensure reliable electrical contact when the PCB is screwed to the meter terminals.

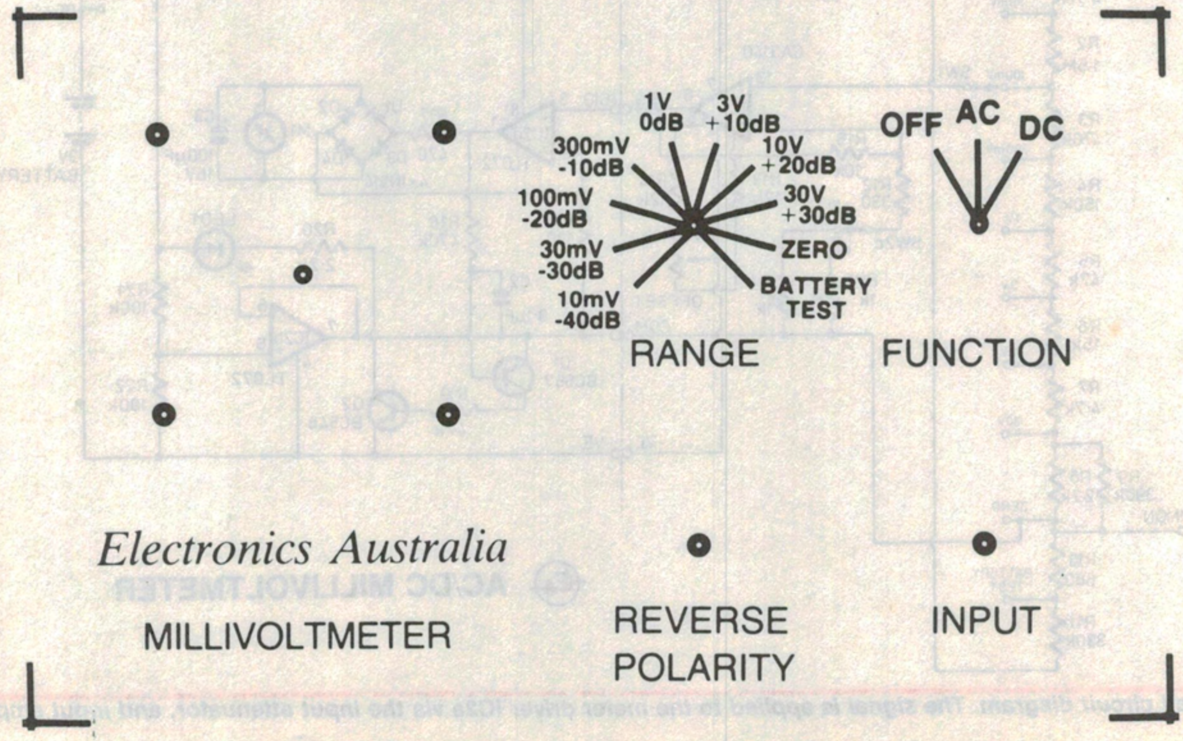
Lengths of hookup wire may now be connected between the two PCBs at the appropriate pads, as per the overlay. The leads from the battery clip can be connected, and a couple of component leg offcuts soldered to the input pads for later connection to the input socket.

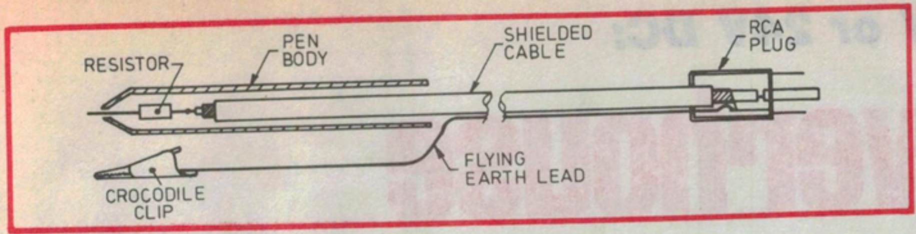
The simplest way to adjust the LED height is to place it loosely in position, and mount the PCB. The LED may then be adjusted to the correct position



Wiring and PCB overlay: Note adjustment holes for RV1, RV2 and RV3.

Above: The artwork for the meter scale.
Below: The full size artwork for the front panel.





Details of simple probe.

in the front panel and the legs soldered in place.

When the PCBs are mounted, the battery may be slid under the meter drive PCB with a small piece of foam rubber to hold it in position. If the millivoltmeter is likely to come in for some rough treatment, the battery may be more securely located on the rear panel by a clamp fashioned from a piece of scrap aluminium.

Calibration

The first step in calibrating the millivoltmeter is to set the offset voltage to electrically balance the instrument. This is achieved by carefully adjusting RV3 for a zero meter reading, while the range switch is in the "zero" position.

The offset adjustment may be a little confusing, as the reverse polarity LED may stay on despite a zero meter reading. This is due to IC2a operating with very little negative feedback when diodes D1 to D4 are not forward biased i.e., no voltage across the meter movement. Therefore the op-amp output will swing either positive or negative until the diodes are forward biased, causing an offset of about plus or minus 0.5V. Hence, the offset adjustment RV3 should be set at a point just before the meter swings towards a positive reading.

Some sort of AC and DC reference voltages are desirable to set the gain calibration trimpots RV2 and RV1. Before adjustment, these voltages should be arranged to give as close as possible to a full scale reading. If a reference voltage is not available, a known (and trusted!) meter could be used for calibrating one of the higher ranges. Naturally, the other ranges will automatically be adjusted as set by the input voltage divider.

When calibrating and using the millivoltmeter on the AC range it should be noted that, like most meters, it is an average reading instrument that is calibrated in RMS voltage. Therefore, non-sinusoidal waveforms may produce misleading measurements. This does not present much of a problem, as most circuit testing is carried out with a sinewave source.

Using the millivoltmeter

A simple probe may be constructed for convenient signal tracing through a circuit. A low value resistor can be fitted in the end of a discarded ball pen body (the type with a narrow opening), with the axial lead out wire forming the probe tip. Shielded cable is then used to connect the probe to a suitable RCA plug, with a flying common lead terminated in a crocodile clip. Of course, any lead used for the input of the millivoltmeter should be well shielded due to the high sensitivity of the instrument.

When measuring voltages it is a good idea to initially select the highest range (30V), and then progressively select the more sensitive ranges until a reasonable pointer deflection occurs. This method will avoid any serious overloads.

The frequency response of the AC range is more than adequate for audio applications, ranging from 10Hz to about 40kHz. Care should be taken to select the AC function in this case, for the rectifying nature of the meter drive will respond to these signals if DC is selected, giving false readings.

The supply current drain of the millivoltmeter is about 7mA. Although this will rise when the reverse polarity LED illuminates, the battery will rarely need to be changed. Its terminal voltage is easily monitored with the battery test facility, which reads 10V FSD and is enabled in the DC function.

Parts list

1 aluminium case, 150x55x95mm
1 meter, 1mA FSD, 58x52mm
1 PCB, code 87m11, 88x120mm
1 1-pole 10-position PCB mount, sealed rotary switch
1 4-pole 3-position PCB mount, sealed rotary switch
2 knobs
1 RCA panel mount socket

Semiconductors

1 CA3140 FET input op-amp
1 TL072 BIFET op-amp
1 BC558 PNP transistor
1 BC548 NPN transistor
4 1N914 diodes
1 5mm red LED

Capacitors

2 0.1uF metallised polyester
1 100uF 16V axial mount electrolytic

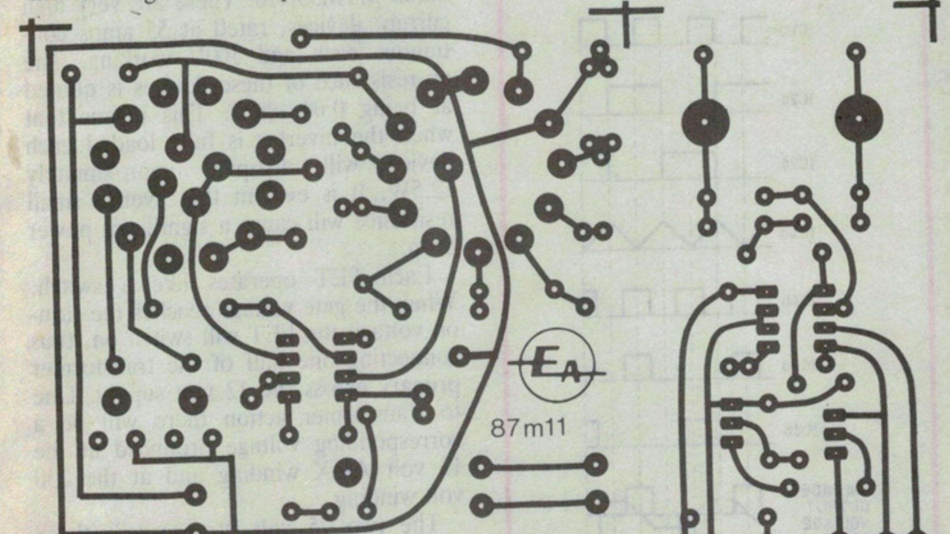
Resistors (all 0.25W 5%: see text)

1 4.7MΩ	2 12kΩ
1 1.5MΩ	1 10kΩ
2 470kΩ	1 4.7kΩ
1 390kΩ	2 2.2kΩ
1 330kΩ	1 680Ω
1 150kΩ	1 470Ω
2 100kΩ	1 330Ω
2 47kΩ	1 120Ω
1 15kΩ	

1 10kΩ horizontal trimpot
2 1kΩ horizontal trimpots

Miscellaneous

9 volt battery and suitable snap connector, hookup wire.



Full size PCB artwork for both the input and meter boards.