PROJECT

Electronic Analog/Digital Multimeter

A versatile test instrument for the workshop.

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The design of an Electronic Analog/Digital Multimeter was a very interesting exercise in compromise. During the course of its development a great deal of respect was gained for the designers of what were considered to be "ordinary" commercial instruments.

The basic electronic circuits for Voltage, Current, Resistance, and AC Measurements are fairly easy to deal with when taken individually, but combining them into a compact hand-held unit with a single range switch is another matter.

After some thought, it was concluded that the only solution suitable for home construction would be a bench meter and to incorporate a number of separate range switches. The idea of a single multi-pole multi-way switch was considered, but the price and the complicated wiring that would be necessary completely ruled this out.

Two advantages of using separate range switches are that the switches can be printed circuit board mounting types — so eliminating wiring and wiring error and that parts of the circuit can be built separately and used individually in other applications.

The indicating device specified is a panel meter with a 100uA sensitivity. This is modified by means of a series resistor to read 0-1V. Almost any standard panel meter can be used, or instead one of the new digital panel meter modules could be added.

The overall performance of the meter is very good; its frequency range when measuring AC voltages and currents is good up to 50kHz and the input impedance of 10 megohms on all voltage ranges gives good accuracy in high impedance circuits where a normal analog multimeter would be useless.

In addition to the standard range the meter has an AC Millivolts circuit which allows audio frequency measurements from 3mV RMS up to 1V and is very useful for testing amplifier signal levels, microphone and pick-up outputs, frequency responses and general signal tracing.

The resistance ranges have the benefit of a linear scale that reads from left to right instead of the usual non-linear, reverse reading scales; also the probes are correctly polarized — that is, red is positive — when making Ohms checks. All resistance measurements are made at a maximum of 100mV so in-situ measurements will not be affected by transistors, ICs and diodes in the circuit.

Other features are that the meter is protected form overloading by a fuse and electronically, and measurements up to 1000V and 10A AC and DC are possible. The meter is built in a fully insulated case for safety.

Circuit Description

The full circuit diagram for the Electronic Analog/Digital Multimeter is shown in Fig. 1. For clarity each section will be described separately.

Voltage

Inputs for voltage measurements are applied to the voltage divider chain made up of resistors R2 to R7. Voltage ranges are selected by S1a, which taps off a proportion of the input voltage from the divider chain and passes it to IC1, the input amplifier circuit.

On the 1kV range an extra resistor (R1) is added to the top of the divider. To avoid having high voltages on the circuit board this resistor is made up from a series combination of values which are sleeved and mounted in the lead to the 1kV terminal (SK3).

The input impedance of the circuit is set by the total combined value of R2 to R7 which is 10 Megaohms. In order to make accurate measurements on all ranges it is essential that the input amplifier circuit have an impedance which is in excess of 50 Megaohms.

Use of a FET input amplifier IC, TL071, and careful board layout ensures that this is achieved. IC1 does not have any gain, but it acts as a buffer circuit with a very high input impedance and a low output impedance.

From IC1 the signal passes to a second amplifier stage IC2 via resistor R32. S1b switches resistor R33 in and out of circuit on alternate ranges to give the 3V, 30V, and 300V ranges.

The combination of resistors R32 and

R33 is such that the signal is reduced by 3 to 1 on each of these ranges but remains unaltered on the 1V, 10V, and 100V ranges. The amplifier IC2 has a gain of 10 and its output is applied to the meter movement via switch S5 when DC measurements are selected.

AC Voltage

The circuit as far as the output of IC2 is identical for AC and DC ranges. Capacitors C1, C2, C3, C4 and C5 correct for the effects of stray capacitance and maintain a level frequency response to about 50kHz.

When AC measurements are made the meter is connected via switch S5 to the output of the rectifier circuit IC5. This circuit takes its input from IC2 and produces a half-wave rectified output which is averaged by the meter movement to give a steady DC reading.

Diodes D3 and D4 in the feedback loop around IC3 are connected so that on negative half-cycles the output stays at 0V, but positive half-cycles are passed normally with a gain of just over 2.

The value of gain is selected so that the meter reads the average value of the incoming signal and indicates the correct (RMS) voltage. As with all meters the accuracy of a.c readings depends on the signal waveform. Sine waves are the most frequently encountered and so the meter is set to read correctly for these.

Diodes D7 and D8 across the meter protect it from being overdriven when switching ranges etc. Diodes D1 and D2 provide similar protection for IC1.

Current

On the Current range the shunt resistors R8

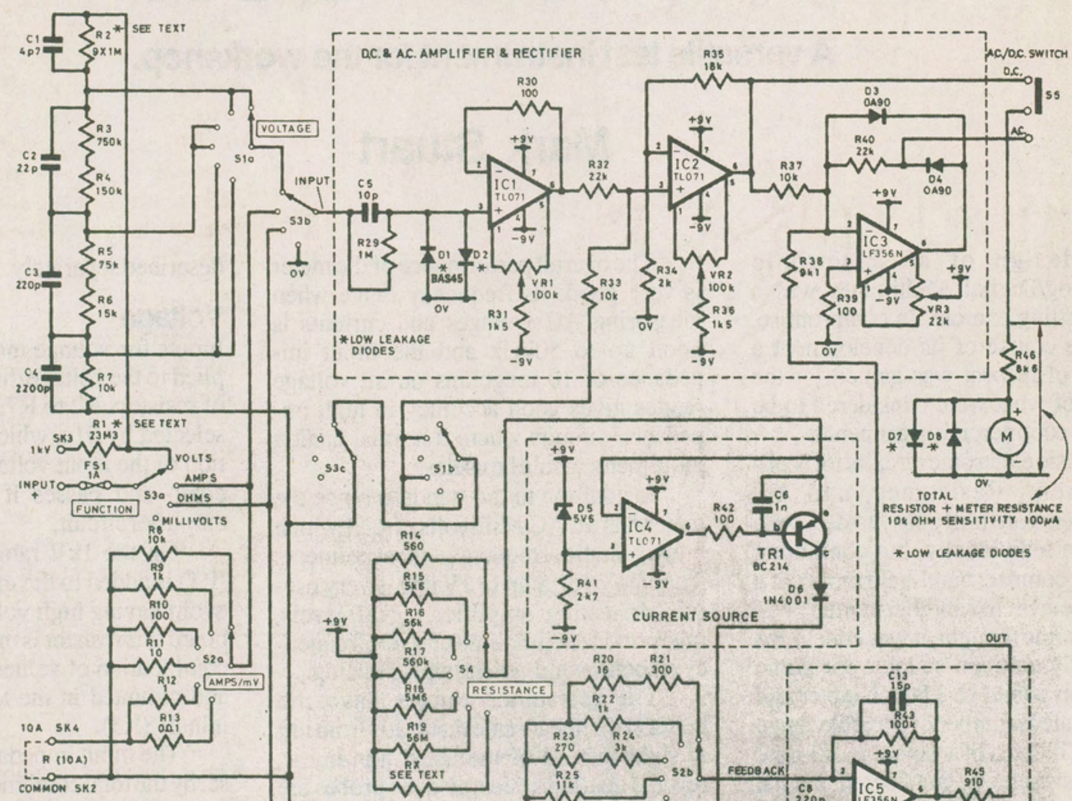

Fig.1. The complete circuit diagram for the Analog/Digital Multimeter. The "active" sections of the circuit are shown within the dotted boxes. The low noise diodes are type BAS45.

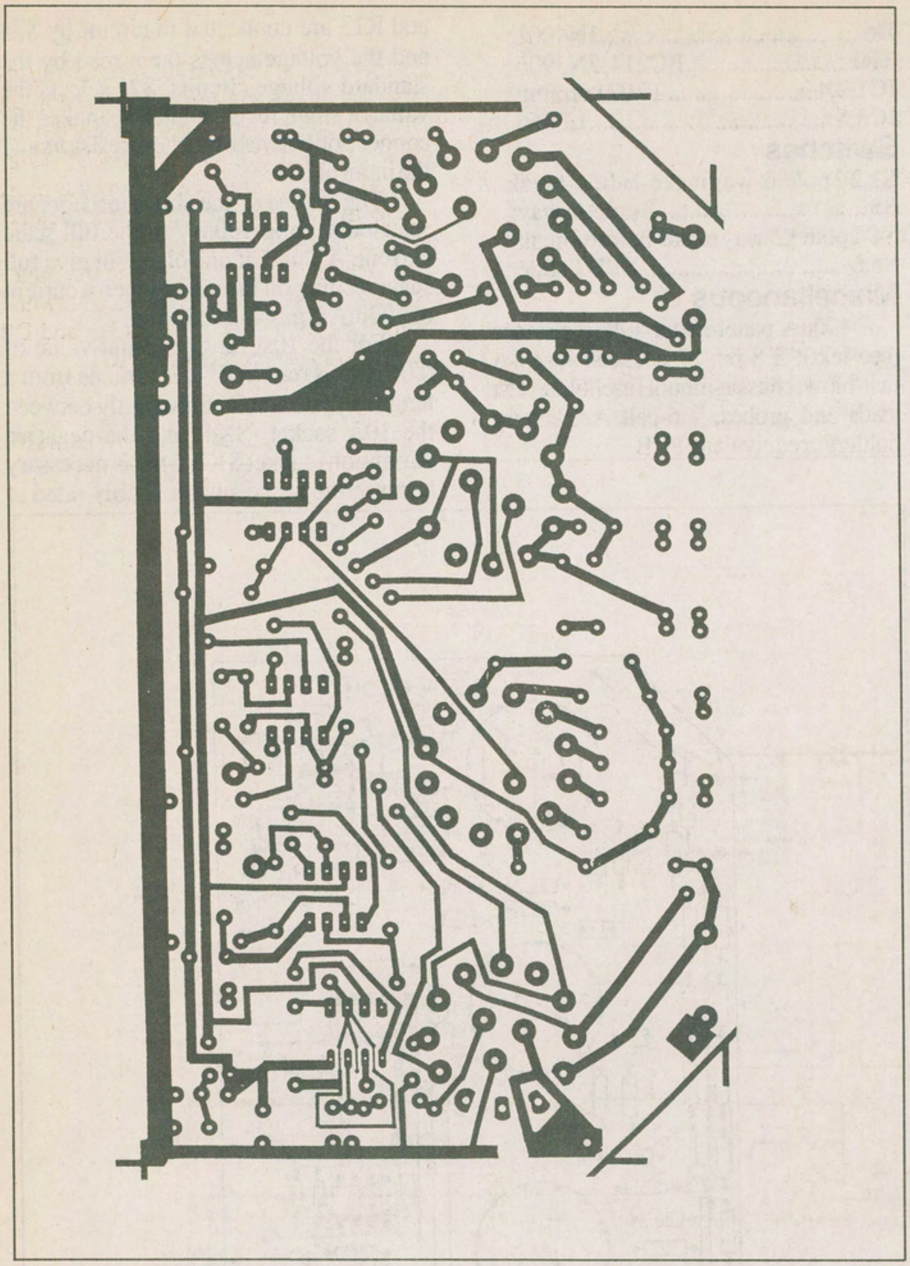

Fig. 3. The full size printed circuit board foil pattern.

1A, and the PCB copper tracks would have to be huge to carry 10A comfortably.

The AC and DC current measurements are treated by the amplifier section in exactly the same way as voltages. The current ranges increase in direct decades (X10) so that the use of S1b is not involved. Switch S3c ensures that this is switched out of circuit on all ranges except voltage.

Resistance

Resistance is measured by passing a known constant current through the resistor under test and measuring the voltage drop across it using the standard voltage circuits.

The current source consists of IC4, transistor TR1, and associated components.

A reference voltage of 5-6V from Zener diode D5 is connected to the non-inverting input of IC4. Negative feedback around IC4 via TR1 and resistor R42 works in such a way that the emitter voltage of TR1 is made equal to this reference voltage. This means that 5-6V appears across whichever emitter resistor is selected by S4.

This constant reference voltage across a fixed resistance value gives a constant current output at the collector of TR1. As the reference voltage is 5-6V a 5k6 range resistor give a current of 1mA. The standard voltage circuit, which is connected via S3b, gives full scale deflection for 100mV. A range current of 1mA thus gives a full scale reading of 100 ohms. Low value resistors drop less voltage and so the reading is directly proportional to the resistor value.

On the higher resistance ranges the current becomes rather too small for comfort. For example on the 100k range a current of only 1uA is required. The 1M and 10M ranges require 0.1uA and 0.01uA respectively. A current of 0.1uA is just about the limit of the circuit, so readings on this range will not be too accurate, and a 10M range is impractical.

The middle resistance ranges are accurate and linear, and much easier to use than a standard meter. No compensation has been made for wiring and test lead resistance, so on the lower ranges 100 ohm and 10 ohm, an offset zero will be present when the test leads are short circuited. This value should be subtracted from any measured resistance value to give the true reading.

AC Millivolts

The measurement of AC Millivolts is made by first amplifying the input to 1V and using the standard rectifier circuit IC3.

The AC Preamplifier, IC5, is connected to IC3 via resistors R45 and R38. The gain of IC5 is set by the feedback resistor R43 and the range resistor selected by S2b. The values of resistors R20 to R28 are chosen to given ranges of 1V 300mV, 100mV, 30mV, 10mV and 3mV. The frequency response is level up to 100kHz except on the 3mV range where it is slightly lower.

When making measurements on the mV range the input of IC1 is connected to 0V by S3b so that stray inputs do not interfere. In a similar way the input of the mV range is shorted out when the input lead is disconnected by use of a switched jack socket (JK1).

The input impedance on this range is set to 100 kilohms by the input resistor R44.

Power Supplies

The Multimeter circuit consumes very low current, but as meters tend to be used frequently it is recommended that two sets of six AA cells be used. Battery holders are often available with clips identical to those used on the small rectangular 9V batteries. If so, the battery holders can use these as

Parts List

Resistors

R1 .... 23.3M (series, see text)
R2 .... 9M (series, see text)
R3 .... 750k
R4 .... 150k
R5 .... 75k
R6 .... 15k
R7,8,33,37 .... 10k
R9,22 .... 1k
R10,30,42 100
R11 10
R12 1
R13 .... 0.1
R14 560
R15 .... 5k6
R16 .... 56k
R17 .... 560k
R18 .... 5M6
R19 .... 56M
R20 16
R21 300
R23 270
R24 .... 3k
R25 .... 11k
R26 .... 43k
R27 .... 3k3
R28 .... 10M
R29 .... 1M
R31,36 .... 1k5
R32 .... 22k
R34 .... 2k
R35 .... 18k
R38 .... 9k1
R39 100
R40 .... 22k
R41 .... 2k7
R43,44 .... 100k
R45 910
R46 .... 8k6 (see text)
R(10A) .... 0.01 wire (see text)
All .25W 1% except as noted

Potentiometers

VR1,2 .... 100k trim
VR3 .... 22k trim

Capacitors

C1 .... 4.7p
C2 .... 22p
C3 .... 220p
C4 .... 2200p
C5 .... 10p
C6 .... 1n
C7 .... 1u 100V
C8 .... 0.22u
C9,11 .... 100n
C10,12,13 .... 15p

Semiconductors

D1,2,7,8 BAS45 low noise (see text)
D3,4 .... OA90 (see text)
D5 .... 5V6 Zener
D6 .... 1N4001
TR1 .... BC214, 2N3906
IC1,2,4 .... TL071 op amp
IC3,5 .... LF356

Switches

S1,2 2 pole, 6-way make-before-break
S3 .... 3 pole, 4-way
S4 1 pole 12-way make-before-break
S5,6 .... DPDT slide

Miscellaneous

100uA panel meter 1.4k resistance (see text); 5 8-pin IC sockets; fuse 1A fast-blow; chassis-mount fuseholder, test leads and probes, 2 6-cell AA battery holders or equivalent, PCB

and R13 are connected in circuit by S3a and the voltage across them read by the standard voltage circuits. S2a selects the value of shunt resistor and S3b makes the connection between the shunt resistors and the input of IC1.

The values of the shunt resistors are selected to drop 100mV at the full scale current. A shunt of one ohm will give full scale reading on the meter when a current of 100mA is passing and so on.

For the 10A range a shunt value of 0.01 ohm is required. This is made from a length of wire connected directly between the 10A socket (SK4) and the negative (Common) socket SK2. This is necessary because the range switch is only rated at

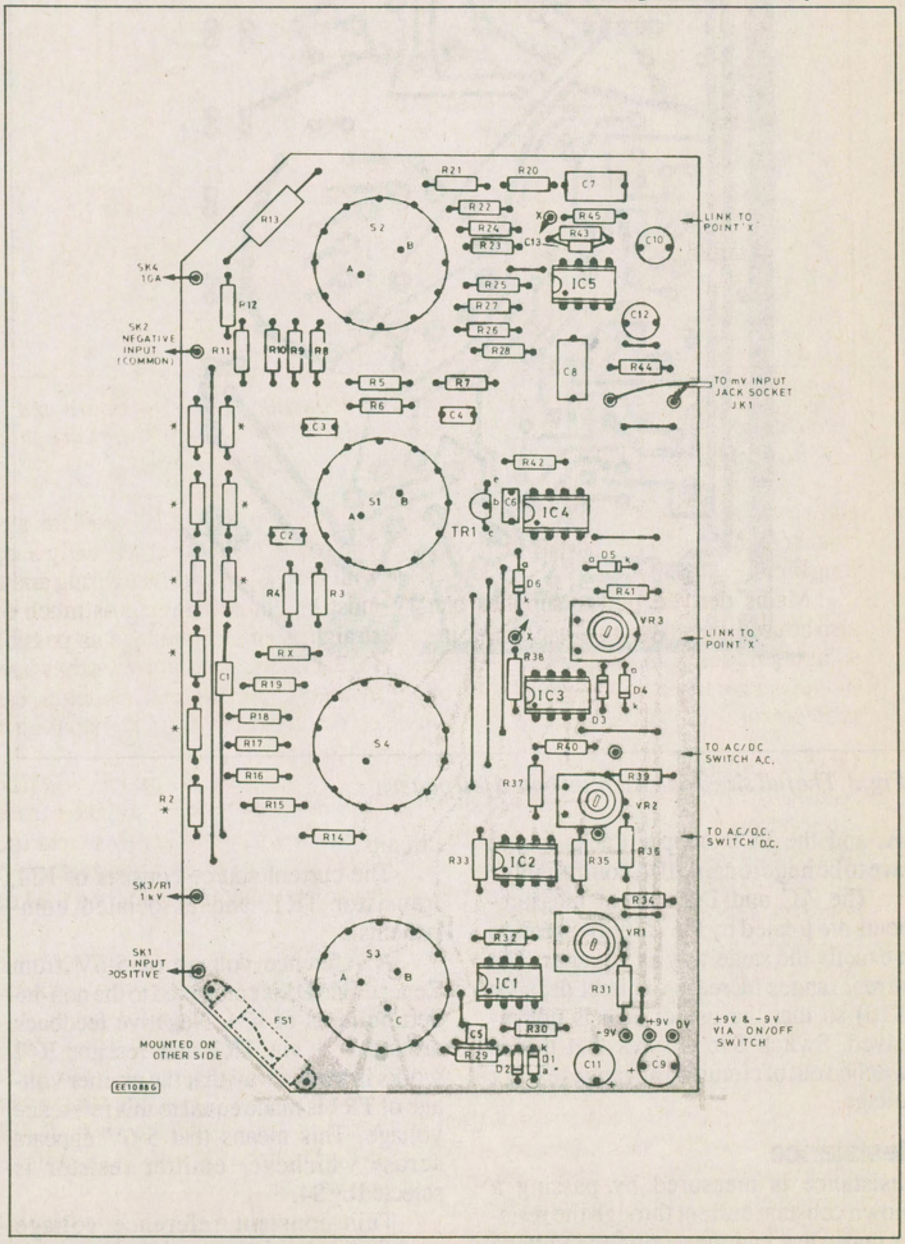

Fig. 2. Component layout on the printed circuit board. Note that the long link wires should be made with plastic insulated connecting wire.

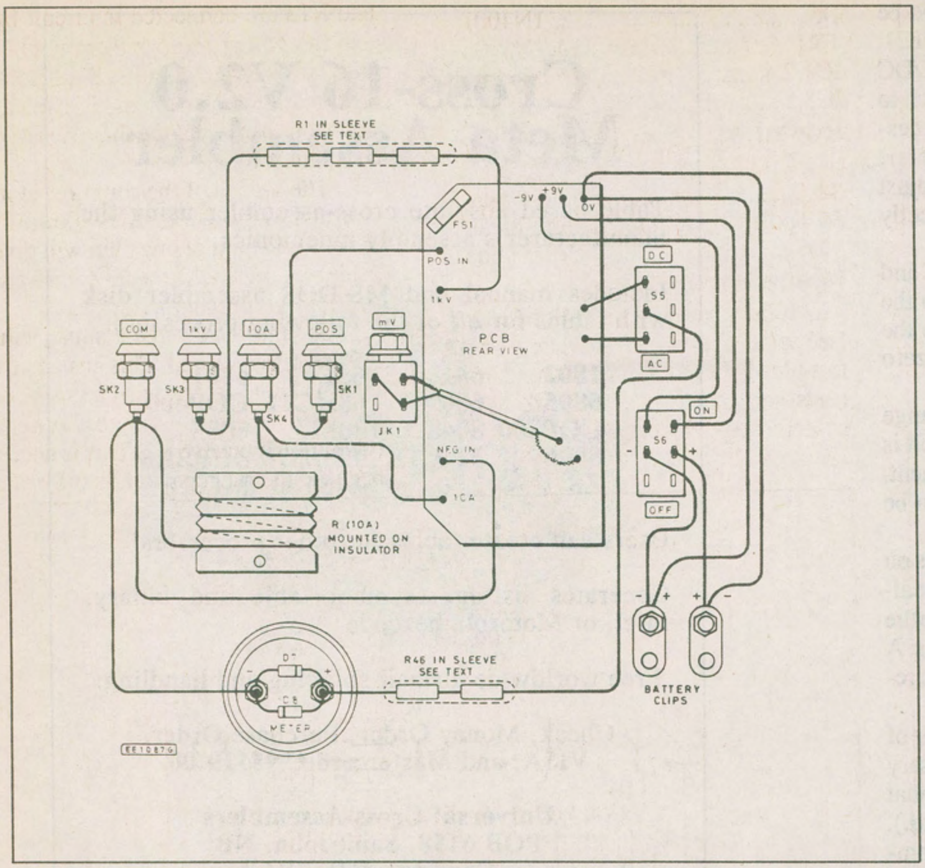

Fig. 4. Interwiring details for the off-board components. The circuit board and components are all mounted on the rear of the front panel. The series resistors are encased in plastic sleeving.

shown in Fig. 4. These can be standard or re-chargeable types, and should give very long life.

Mains derived power supplies can also be used, but take care to use double insulated circuits *without* a ground on the output side as this could cause all sorts of problems with ground loops.

Construction

As the circuit is all built on a single printed circuit board the assembly is fairly straightforward. Fig. 2 shows the component layout and Fig. 3 the printed circuit board track pattern, full size.

Begin assembly by fitting the wire links as shown. The longer links should be made with insulated wire while the shorter ones can be made from offcut resistor leads.

As there are a lot of resistors and most of them carry the five-band one percent color code system, it is necessary to be rather careful to get the correct values in the right places. Any errors will give odd ranges which may not be easy to spot as the meter may appear to be working perfectly.

Sockets should be used for all ICs. The rotary switches are usually supplied with loop tags for direct wiring and these must be cut off leaving as much of the straight stems of the tags as possible. If PCB-mounting rotary switches are not available, panelmount switches can be used with the appropriate hookup wires run to the PCB.

Switches S1, S2 and S3 will fit more than one way around, so take care to set them fully counterclockwise and use the flat of the shaft as a guide to get them right. Remember that the pointer on the knob is exactly opposite the flat on the spindle. If you get it wrong and don't want to unsolder the switch, screw fix knobs are a good alternative way out.

Capacitor C1 is mounted between two distant points — its leads must be sleeved and may need extending to fit the board centers. Make sure that all diodes, and capacitors C9 and C11 are the right way around.

The final component to be fitted to the board is the fuseholder which is fitted to the track side to keep easy access to the fuse. Once the board assembly is complete connect the necessary wires to the board. The mV input should use shielded cable, the other input socket connections should be made with 16/0.2 wire.

Resistors for the 1KV socket should be fitted in a length of sleeving between the board and the input socket. The 10A shunt is made from a 71cm length of 18swg enamelled wire connected directly between the 10A socket and the negative (Con) socket SK2. The wire can be loosely wound on a flat piece of insulating material.

The wiring diagram, Fig. 4, shows how the shunt can be fitted and the wiring to the other parts of the board from the sockets.

Resistors and Diodes

R1 is 23.3M, and is made up by using 2 20M and one 3.3M soldered in a series string. R2 is 9 1M resistors in a series string. These should be enclosed in a short length of plastic tubing.

R46, in series with the meter coil, should be chosen so that R46 plus the coil resistance add up to 10k. The chosen value of 8600 ohms will work with 1400-ohm meters.

The diodes D1,2,3,4,7, and 8 are selected for very high performance. However, since these diodes are very difficult to find, you can use the common 1N914 or 1N4448 without much loss of performance.

Testing And Setting Up

The thorough testing of a meter of this type presents quite a problem. The wide range of accurate voltages and currents necessary to check each range fully is not likely to be available even in electronics workshops. The best way is to make comparisons with other meters using whatever sources of voltage and current are available. It is possible that a local training center, school or college will be able to help, so ask around.

Fine tuning of capacitor values C1, C2, C3, C4 and C5 may be undertaken by those determined to extract the very best from the meter. There components affect the frequency response on the AC Voltage ranges. Capacitors C1 and C5 in particular have a large effect and should be changed only if a good reliable sine wave source of 0-100kHz or more is available.

If no test gear is available it is safe to say that the meter should work accurately first time provided no errors are made in assembly.

There are three presets that must be set up to remove the zero offsets of IC1, IC2 and IC3. To do this, set the AC/DC switch S5 to DC and the Range switch to mV. Link pin 3 of IC2 to 0V and if necessary adjust VR2 to zero the meter. Remove the link and if necessary adjust VR1 for zero. These two are now correctly set.

Next set the AC/DC switch to AC and turn VR3 until the meter deflects to the right. Back of the setting of VR3 to the point where the meter just touches zero and the settings are complete.

The accuracy of the Ohms range depends on the Zener diode D5 which is specified as a five percent component. More accurate voltage references can be obtained and substituted if required.

The value of resistor R46 depends on the meter being used. Its value can be calculated easily as its function is to make the meter resistance value up to 10 kilohms. A meter of four kilohms resistance thus requires a six kilohms resistor and so on.

It is also possible to use meters of other current ratings, all that is necessary is to set the meter and series resistor so that 1V gives a full scale deflection (f.s.d.). Thus a 1mA meter would need a combined meter plus series resistor value of one kilohm. A 50uA meter, 20 kilohms; a 500uA meter, 2 kilohms, etc.

On AC ranges the averaging effect of some types of meter may be affected by the diode (D4) in the drive circuit. A 1k resistor from D4 cathode to 0V line overcomes this and allows any type of meter to be used.

Safety

For complete safety an *insulated* case is *essential* where high voltage readings are to be made. It is also necessary to add some shielding to the meter electronics.

The best way to combine these two functions is to use a plastic case with a metal front panel overlaid with a Paxolin insulating panel. The metal panel should be connected to the 0V point in the circuit.

Decibel Ranges

The dB Range on the meter is set to be accurate on the AC mV Ranges. On the 1V AC Range (mV) the 0dB point represents the universal 1mW in 600 ohms. Each range down from this subtracts exactly 10dB so relative measurements are easy.

The use of dB scales is a difficult subject for beginners and it is not intended to go into details here. ■