Working With Meters – 3

To conclude our short series of articles dealing with meter movements and their use, the author describes here how to avoid some of the common pitfalls encountered in everyday measurements. He also gives a description and constructional details for a useful battery testing device.

by PHILIP PIK

We saw last month how the insertion of an ammeter into a circuit could change the magnitude of the current flowing through that circuit. Let us look at this effect a little more closely this month, and see just how important it becomes in high current measurements.

A common situation where measurements of high currents must often be made is in automotive maintenance and repair. Here one may at times need to measure the output from a battery charger, or measure the output from the generator in order to adjust the regulator.

Let us consider that we have a 6-volt electrical system, and that we wish to measure currents of up to 50 amps. As it is our aim to find the effect of the ammeter on the current before and after its insertion, we must first find the resistance of the complete circuit.

This is made up of the resistance in the wiring, the load and the internal resistance of the battery. We do not, however, have to know their individual values. All that is required is to find the total resistance which will give a current of 50A at 6V, by applying Ohm's law.

Working this out gives us a resistance of 0.12 ohms – a pretty low value. Let us see now how the ammeter resistance is likely to compare with this figure.

Assume that we have an ammeter which uses a 100mV FSD movement. This means that the terminal resistance of the ammeter will be very close to 0.002 ohms, as calculated in last month's article. Expressed as a percentage of 0.12 ohms, this is only about 1.67%. On this basis, it may seem that we could ignore the effect of the ammeter on the current in the circuit.

Unfortunately, however, the ideal case just described very rarely holds in practice. The main reason for this is that generally there are additional resistances introduced into the circuit when the ammeter is physically connected into it. There is the resistance due to the leads connecting the ammeter to the circuit, and there are the additional hidden resistances of the connections themselves. These are all effectively placed in series with the circuit, and this usually causes the current flowing to be significantly less than when the ammeter is not in circuit.

Because these additional resistances are external to the ammeter itself, they do not cause the meter to give an inaccurate reading of the current flowing when it is in circuit. But the effect of the resistances is that the current flowing with the meter in circuit, tends to be significantly less than without it. In other words, we end up with an accurate measurement of an abnormal condition, which is almost as misleading as a faulty reading of the normal current.

The remedy for this problem should be fairly clear: connect the ammeter into circuit using the shortest convenient connecting leads, and use stout cable for these leads. Also make sure that all clips, lugs, screws and washers used to make the connections are adequately sized, and scrupulously clean. There is something to be said for the popular "quik-fit" type of automotive connector, which provided it is clean offers a very low order of contact resistance.

Just how important these matters are may be gauged from the fact that even two short leads of equivalent cross-section to 10G copper wire can contribute .0012 ohms to the circuit, while modest oxidation on the surface of the connecting clips can add a further .04 ohms. This added resistance would be sufficient to cause an error of over 50% in a reading of 50A in a 6V electrical system – a 50A reading on the ammeter would correspond to about 78A under normal conditions.

So much for the ammeter, then, and the necessary care in using it. Let us next discuss the voltmeter. This has similar limitations to the ammeter, except that in this case the limitations are more associated with the instrument rather than with the physical connection of it into circuit. As an example let us examine the use of a typical 20,000 ohms per volt multimeter to measure the collector voltage on the transistor in the circuit of figure 1.

Let us assume that the DC voltage ranges we have available on the meter are 1, 10, 100 and 1000 volts. As the circuit has a supply voltage of 9V, the 10-volt range would thus appear to be the most appropriate one to use initially. On this range the 20,000 ohms/volt meter will have a loading resistance of (20,000 x 10) =200K.

As the type of amplifier stage shown is normally designed so that the quiescent voltage present at the collector is approximately half the supply voltage, this means that the effective DC resistance of the transistor will be approximately 470K. The effect of the 200K resistance of the voltmeter in parallel with the transistor will thus be quite drastic, lowering the total resistance from collector to ground to approximately 140K.

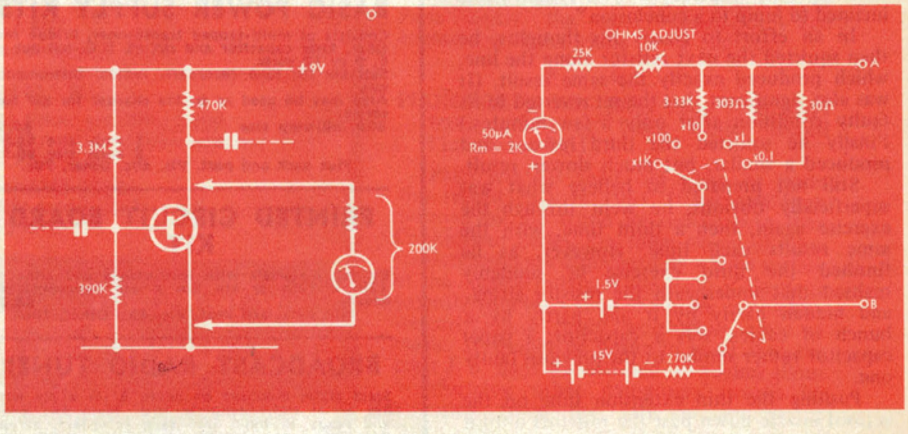
With the meter in circuit the collector voltage will thus no longer be half the supply voltage or 4.5V, but closer to 2.1V. And this voltage will be registered quite faithfully by the voltmeter. The only problem is that this is not the normal voltage at the collector when the meter is not present!

From this it may be appreciated that the use of the common multimeter is quite limited in high impedance circuits. About all that be deduced from the reading is that the transistor does not have a short circuit between collector and emitter. This leads us to the conclusion that if measurements in circuits of this kind are to have any meaning, we need a high resistance measuring device such as a VTVM or its solid-state equivalent. These instruments generally have an input impedance of 10M and consequently any errors introduced by using one of these is practically negligible.

This does not mean that there is no place at all for the multimeter in high impedance circuits. Provided care is taken in its usage, quite useful measurements may be made. In general, if reasonably reliable results are required, a rule of thumb is that the resistance of the meter be at least five times that of the circuit across which it is connected. In the circuit of figure 1 this would mean a meter resistance of about 3M, which would rule out even a 100,000 ohms/voltmeter. However there are many circuits where the resistances involved are of a much lower order, allowing accurate results to be obtained with a modest 20,000 ohms/volt multimeter.

As an example of a third type of measurement pitfall, let us look at the simple series-type ohmmeter. In particular, let us study the ohmmeter circuit of last month, reproduced here for convenience in figure 2. We will consider the effect of the "Ohms Adjust" control on the operation of the circuit in relation to its accuracy.

It may be remembered from last month's discussion that the function of this control



The effect of loading a typical transistor stage with a multimeter is illustrated in figure 1, at left. Figure 2 at right shows the basic ohmmeter reproduced from last month's article. Sources of error in this circuit are discussed in the text.

was to compensate for decaying battery voltage. Its range was made such that it could be varied from zero to 10K.

Let us consider the X100 range, and the effect of varying the control setting upon its accuracy. When the 1.5V cell is new, the control is presumably set so that the total circuit resistance between the meter terminals is 30K. Hence a 30K resistor connected to the terminal produces its correct reading – exactly half FSD. But when the battery voltage drops such that the control must be set to minimum resistance to produce FSD for shorted input, the total internal resistance will be only 27K – that of the meter and its series resistor.

In this condition a 30K resistor connected to the terminals will not read 30K, but will read approximately 33K. In fact it will be a 27K resistor which will produce the mid-scale "30K" reading, so that the readings will be approximately 10% high – a significant error.

This argument is somewhat simplified, because in practice the internal resistance of a cell increases as its voltage drops. Hence the rising cell resistance will tend to compensate for the reduced value of the "ohms adjust" pot. But the error still tends to be quite significant.

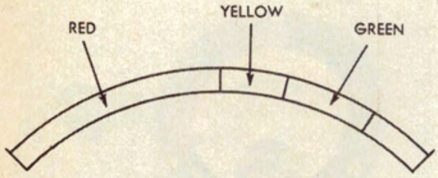


Figure 3: The meter scale of the prototype battery tester. The use of colours as indicated is recommended.

Luckily, the X1K range does not suffer to the same degree from this problem. Here the effect of the control setting is only minimal as the total circuit resistance changes by only a small percentage. The midscale reading of 300K has a tolerance of less than + 2%.

The remaining X10, X1, and X0.1 ranges are also better off. On the X10 range the meter is shunted by a resistor at least 1/10th its own equivalent resistance. Thus the effect on the overall accuracy due to a change in control setting is minimal. The X1 and X0.1 ranges suffer even less, as the meter and control are shunted by even smaller resistors.

Before closing the discussion on this section, it should perhaps be pointed out that there are alternative, slightly more complex circuits which reduce to some extent the relatively large errors encountered on the X100 range. However, discussion of these more specialised circuits falls outside the scope of this article.

Having dealt briefly with some of the pitfalls to be avoided in measurements, we will conclude this article with constructional details for a flexible battery tester. But just before we launch into the description, let us have a brief look at the requirements for this kind of device.

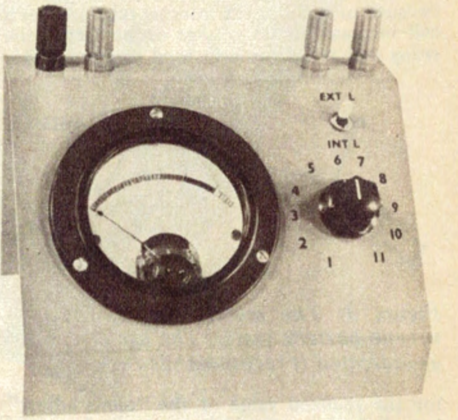
The first requirement, naturally enough, is that it must measure the battery's output voltage. But measuring this alone, without regard to its output current capability, leads to incorrect conclusions.

The reason for this becomes fairly obvious if one considers the nature of a dry cell. Like most other practical power sources, a dry cell can be thought of as a series combination of a voltage source in series with a resistance. And both the voltage source and the internal resistance change in value over the useful life of the battery. The voltage gradually drops, while the resistance gradually rises.

In order to obtain a true indication of the condition of a dry cell or battery it is therefore necessary to take both its voltage and internal resistance into account. And the best way to do this is to measure the terminal voltage of the cell or battery when it is being "loaded" – ie, when it is delivering a certain output current. The current is normally set at a value close to that demanded from the cell or battery under normal working conditions, as this gives the best indication as to whether it is still capable of doing the required job.

As each size and type of cell and battery is designed for a particular type of service, it is actually possible to nominate "typical" test current levels for most types. Although not usually supplied by the battery manufacturers, this information is often obtainable on request.

We have prepared a table showing the voltages and test currents for some of the more common "Eveready" types, and this is reproduced. Note that we have grouped those having the same output voltage and test current. There are eleven groups in all, arranged in ascending order with regard to their output voltages. Sufficient space has been left alongside the Eveready type numbers to include other manufacturer's designations. The reason for this should become evident later.

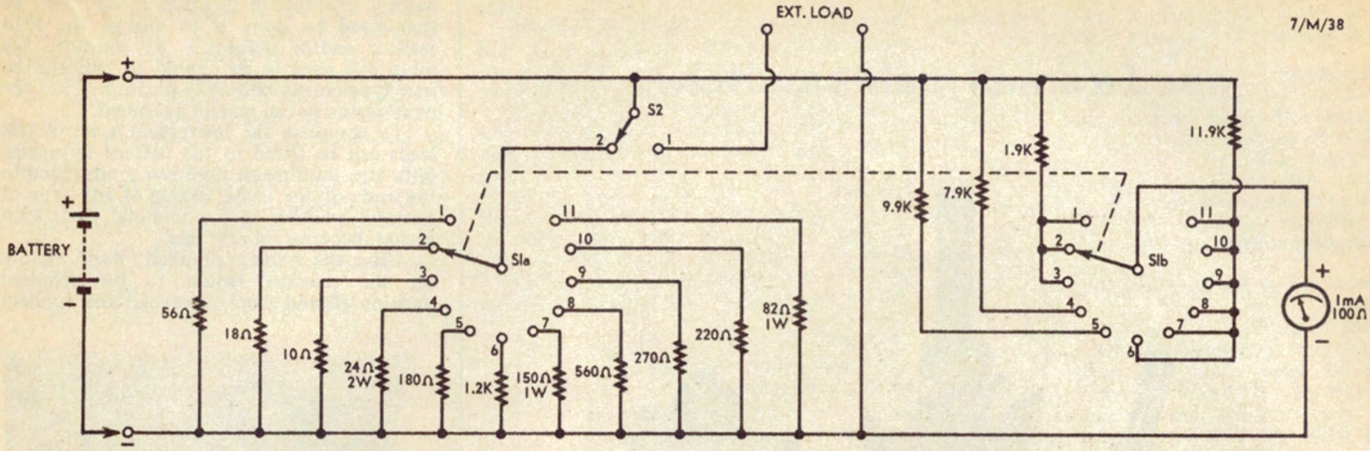


The battery tester. The terminals at left connect to the battery.

Let us now look at the circuit for the battery tester unit, which is designed to test each type of battery by measuring its terminal voltage while the appropriate load current is being delivered. It may be seen that the unit consists basically of a multi-range voltmeter, combined with a series of loading resistors. A two-pole 11 position switch selects the voltmeter multiplier resistor and loading resistor required for each of the battery groups shown in table 1. Switch section S1a selects the load resistor, while S1b selects the voltmeter multiplier.

Provision has also been made to connect an external load resistor into circuit, by switching S2 to position 1. This allows the test current for any battery to be varied above or below its nominal value, and is also useful for testing batteries other than those directly catered for by the fixed ranges. Naturally the output voltage of such batteries should correspond to one of the ranges provided, ie, 1.5, 6, 7.5, or 9 volts.

To find the value of the external load resistor, simply divide the battery's voltage by the required load current. For example, if the



The complete circuit diagram of the battery tester. Note the provision for switching in external load resistors.

UNIVERSAL BATTERY TESTER						
S1 POS. No.	EVEREADY TYPE Nos.			NOTES	VOLTAGE	TEST CURRENT (mA)
1	915 1015				1.5	25
2	935 1035				1.5	80
3	950 1050				1.5	150
4	509				6	250
5	2510				7.5	40
6	216				9	8
7	286				9	60
8	2362				9	15
9	2364 276P				9	30
10	2512				9	40
11	2761				9	100

This table shows the various test currents for some of the Eveready batteries. Space has been allowed for the type numbers of other makes.

battery voltage is 1.5V and the required load current 150mA or 0.15A, then the load resistor is 1.5/0.15 which is 10 ohms. The power rating of the resistor should also be worked out and this may be found by using the relationship P=EI. For the resistor in question this is 1.5 x 0.15=0.225W. A half watt resistor would probably be the nearest available power rating. In fact, inside the unit we have used 1/2 watt resistors throughout except in three cases where a higher power rating was needed.

If a movement different from the one specified in the circuit is used, the multipliers will need to be recalculated using the equation given last month.

Construction of the tester is fairly straightforward and should present few problems. The circuitry may be built into a closed box, perhaps one with a sloping panel as we have used, or in any other suitable shape or form. Layout is not critical.

In order that the battery state can be determined at a glance, the meter scale should be marked off in three sections, as illustrated in figure 3. The "good" sector (green) indicates a basic battery cell voltage between 1.3 and 1.7 volts, the "serviceable" sector (yellow) a voltage between 1.0 and 1.3, and the "bad" sector (red) voltages below 1.0 volt.

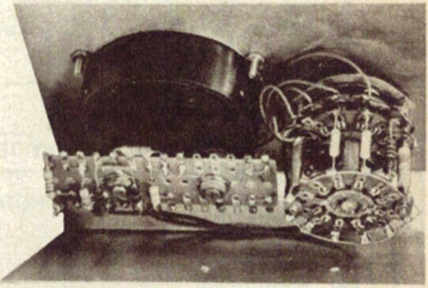
Mounting of the various circuit components will depend on the size and shape of case in question. However, by far the most convenient way of mounting the resistors, especially the load resistors, is by spacing them between two switch wafers, one of which is inactive and acts as a support only. As is evident from the illustrations, this method saves a lot of wiring, whilst at the same time it provides rigid support for the resistors. Space did not permit us to mount the multipliers in a similar manner, but as there were only four of these it was a simple matter to mount them behind the meter on a separate length of tagstrip.

As the front view of the instrument shows the panel lettering has been kept simple, especially around the selector switch. Numerical index numbers rather than the more lengthy battery type numbers have been used, to prevent the labelling from becoming cluttered. The table mentioned earlier can by glued to the back of the tester where it is in a convenient position for reference.

In this way any additions or alterations can be made more easily. For example, if it is required to permanently change the type of battery checked in position 7, say, then all that need be done is to change the load resistor and/or multiplier. In addition, the table will need to be altered to indicate the new type corresponding to position 7, but the panel lettering can remain unaltered.

To complete the instrument a set of test leads can be fitted to the battery terminals. With two multimeter-type test prods fitted to the ends of the leads, testing of any type of battery, whether it has terminal posts or a socket, becomes an easy task.

Using the tester is simplicity itself. Simply set the selector switch to the required position (found from the table) and connect the test prods to the battery. If the meter reads in the green sector, the battery is in good condition; if it reads in the yellow sector, the battery is still serviceable. But if the pointer lies in the red sector, the battery can be considered "flat" as far as its use in most electronic equipment is concerned. It might still be useful in some applications, however, such as in torches and some toys.



This photo shows how we mounted the resistors between two switch wafers.

This draws to a close our discussion on the battery tester, and indeed to this short series of articles. We hope that they have been of some help to those wishing to gain a better understanding of meter movements and their uses. Perhaps they have also given some readers the incentive needed to finish off that job planned long ago – that milliammeter in the PA stage of a transmitter, that voltmeter across the HT output of a power supply, or that battery tester the shop has been in need of for so long.