Chapter 4

Digital multimeter circuits

As we have seen, an ADC in only capable of handling DC voltage inputs.
When, as in a multimeter, other quantities such as DC current, AC voltage and current and resistance have to be measured, these quantities first have to undergo analog conversion to a DC voltage.
Although the subject of analog conversions might be thought to be a bit outside the scope of a digital instrument course, we need to say a little about these techniques in order to provide a better basis for understanding the considerations concerning the accuracy of digital voltmeters given in chapter 5.

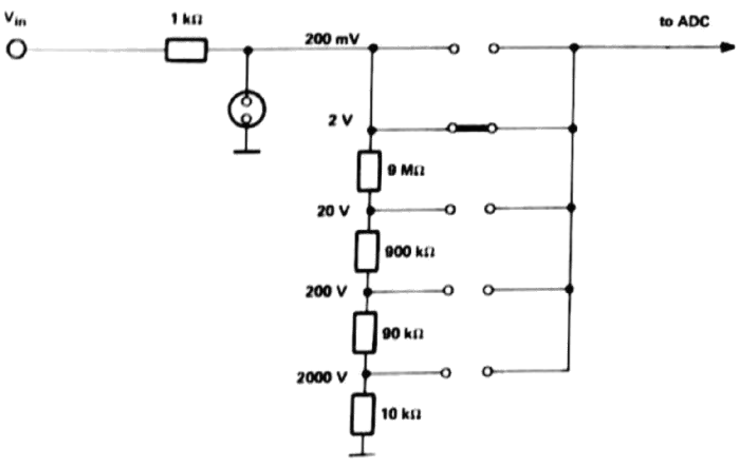

Fig. 4.1. A simple DC attenuator.

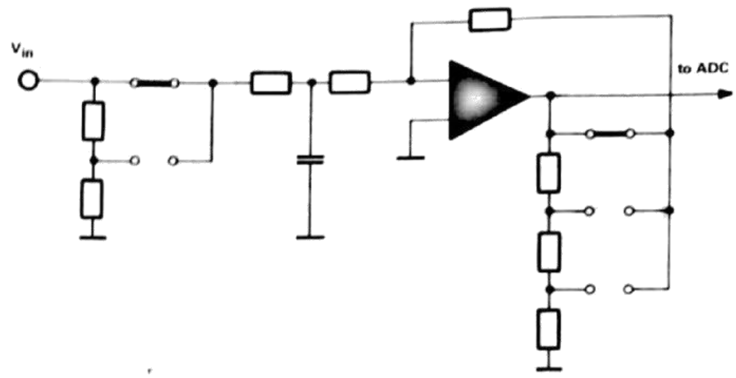

Fig. 4.2. An attenuator with an operational amplifier connected as a variable gain pre-amplifier.

DC Voltage attenuator

The DC signals that can be handled by the input of an ADC are in general limited to less than 10 V. This means that DC voltages of more than 10 V have to be attenuated in the input stage of a DMM before they can be passed on to the ADC. A simple form of attenuator which can be used for this purpose is shown in fig. 4.1.
In the 200 mV and 2 V settings, the input signal is applied directly to the ADC. In the other settings, it is attenuated first. It will be seen that the attenuator offers a fixed input impedance of 10 MΩ in all settings.
A voltage overload device is included in the circuit to protect it against excessive input voltages.
A second solution which is often used is to employ an operational amplifier connected as a pre-amplifier with adjustable gain, as described in chapter 1. The number of attenuation steps that can be realized in this way is limited by the dynamic range of the amplifiers; a voltage divider giving a one-step preattenuation of e.g. 1000 : 1 must therefore be included in the circuit to allow the full range to be covered. An example of such a circuit is shown in fig. 4.2.

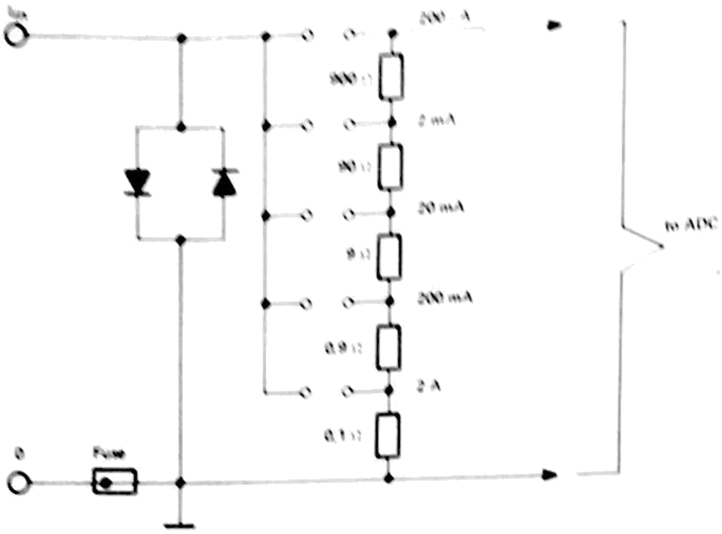

Fig. 4.3. Current-to-voltage converter.

Current-to-voltage converter

DC currents are converted into voltages by shunts in such a way that the voltages across the shunt at full range is the same for all current ranges, and is as low as possible. To provide overload protection in the lower current ranges, two diodes in anti-parallel are added to the circuit: before the voltage across the shunt resistors can assume a dangerous value, one of the diodes starts conducting and the fuse will blow (fig. 4.3.).

AC-DC converter

A widely used system for AC-DC conversion is the average detector described below. More reliable results are given by a true RMS converter, as the accuracy of the latter is independent of the waveform (see chapter 7); but this solution is more expensive. In the average detector, two diodes D_1 and D_2 are arranged in the feedback loop of an operational amplifier OA (fig. 4.4.).

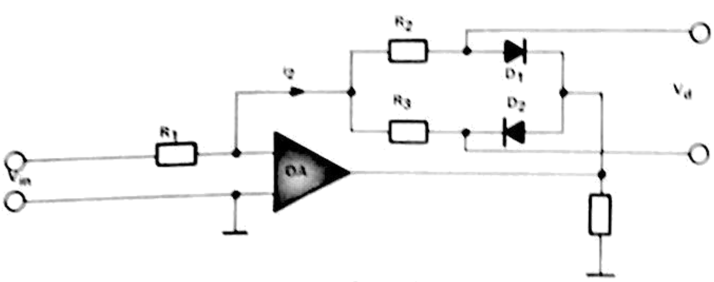

Fig. 4.4. An average detector as AC-to-DC converter.

$i_2 = \frac{V_{in}}{R_1}$ (see chapter 1)

i_2 passes through R_2 or R_3 depending on the polarity of the input signal, so:

$V_d = i_2 \times R_2 + 0 \times R_3$ or $V_d = 0 \times R_2 + i_2 . R_3$;

and when R_2 and R_3 are equal, then $V_d = V_{in} \frac{R_2}{R_1}$

V_d is thus a linear function of V_{in}.
The advantage of this system is that it gives linear detection from very low AC levels. This can be shown as follows.
As long as the diodes are cut off, the resistance in the feedback loop of the amplifier is very high, so the gain of the circuit is approximately equal to the open-loop gain and is thus very high too (of the order of 5×10^7). The diodes start to conduct at about 0.5 V, i.e. at an input voltage V_{in} of $\frac{0.5\ \text{V}}{\text{open-loop gain}} \approx 10$ nV;

voltages of or above this value can thus be detected.

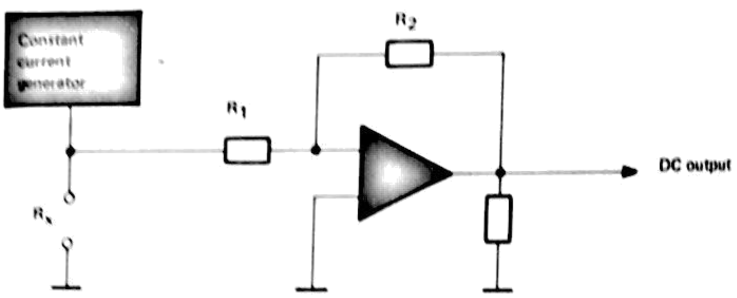

Fig. 4.5. Resistance-to-voltage converter.

Resistance-to-voltage converter

Resistances are measured by passing a constant current through the unknown resistance R_x and measuring the voltage across it. A possible circuit is given in fig. 4.5. As very high resistance ranges would require very low currents with this set-up, an alternative version can be used making use of the fact that the gain of the operational amplifier depends on the ratio R_2/R_1 (see fig. 4.6.). Now the input voltage is constant (fixed current through fixed resistance), while the output voltage is $R_x \frac{V_{in}}{R_1}$, i.e. proportional to R_x and the proportionality constant here is far lower than in fig. 4.5.

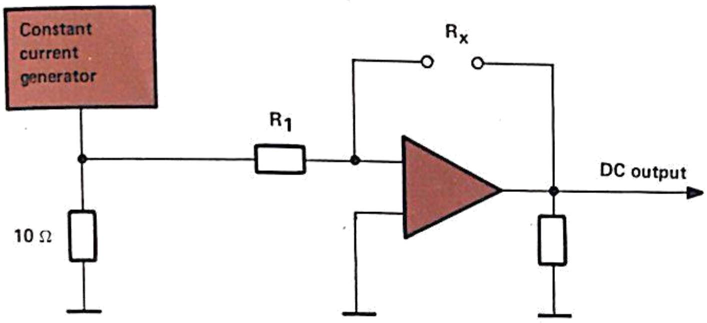

Fig. 4.6. Resistance-to-voltage converter for very high resistance ranges.

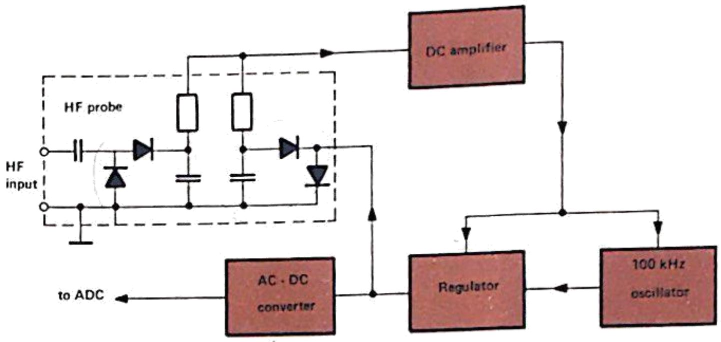

Fig. 4.7. HF-to-LF converter.

HF-to-LF converter

For the sake of completeness, we will close this chapter with a description of a system that can be used to permit HF measurements; such a system is used e.g. in the Philips Multimeter PM 2527.

The DMM circuitry which we have describing so far is not suitable for the measurement of very high-frequency voltages. However, this problem can be got round in an elegant way with the aid of the circuit of fig. 4.7.

The input HF signal and an internally generated 100 kHz signal are compared after detection in the HF probe. The resulting difference signal is fed to the DC amplifier, whose output is used to control the amplitude of the 100 kHz signal. As the loop gain is high, the amplitude of the resulting 100 kHz signal is virtually the same as that of the original HF one. All we now have to do is to measure the amplitude of the LF signal in the normal way in the LF measuring circuit. Linear measurements are obtained from a level of some mV.

Questions:

Check the answer(s) you believe to be correct.

Q.4.1. Figure 4.8 shows a full-wave rectifier circuit. The diodes have a forward voltage drop of 0.5 V; they will therefore start to conduct at an input voltage V_{in} of:

A 50 mV

B 1 μV

C 5 μV

A	
B	
C	

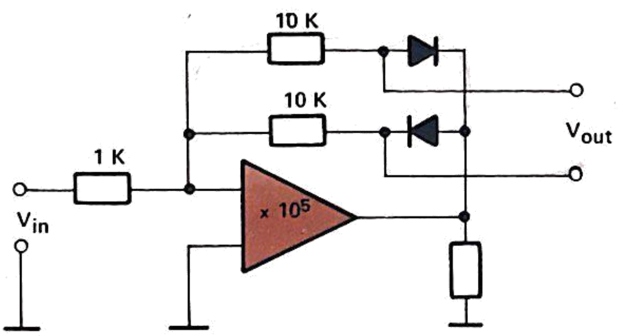

Fig. 4.8.

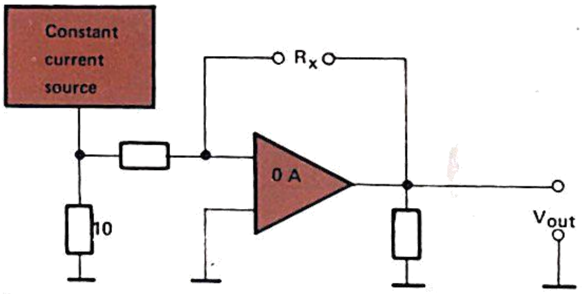

Fig. 4.9.

Q.4.2. The resistance-to-voltage converter of figure 4.9 is used to measure:

A high resistances

B low resistances

C both A and B

A	
B	
C	

The answers to the problems will be found at the end of the book.