MEASUREMENT TECHNIQUES (4)

by F.P. Zantis

This month's instalment deals with a very important measurement: that of resistance. This measurement is important not only in faultfinding, but also in design and development. It is, unfortunately, not possible to deal with the gamut of methods available: only the most common ones will be discussed

VIRTUALLY all multimeters have several ranges for measuring ohmic (also called true or d c) resistance The battery provided in analogue types is there for one purpose only: the measurement of resistance The two most common methods of measurement use either a constant-voltage source or a constant-current source

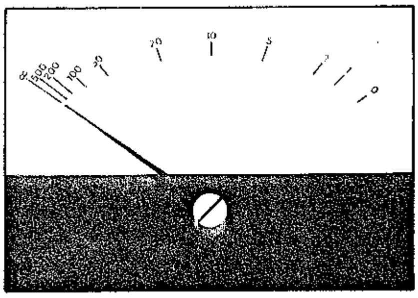


Fig. 24. An analogue meter becomes difficult to read at the left-hand side of the scale

In the first, a constant voltage. U_c. is applied across the component under test: the resulting current I_r is used as the basis of the resistance measurement: $I_r = U_c / R_X$. where R_X is the resistance of the component under test Since I_r is inversely proportional to R_X, a separate scale is required. which is calibrated in ohms (or multiples thereof) and runs from right to left that is, "0" is at the right-hand side of the scale—see Fig 24 It should be noted that accurate measurements are only possible over the right-hand half or three-quarter of the scale

The basic circuit for this method of measurement is shown in Fig. 25 The "0" value (meter terminals short-circuited) is set with the aid of the potentiometer. This obviates any circuit properties affecting subsequent measurements

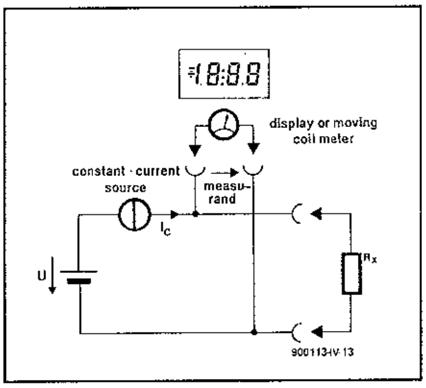


Fig. 26. Basic circuit for constant-current measurements

The fundamental circuit for constant-current measurements is shown in Fig 26 In this method, a constant current, I_c, is passed through the component under test and the consequent voltage. U_r, across it is the basis of the resistance measurement: $U_r = I_c R_X$ Note that in this method U_r is directly proportional to the resistance A separate scale is, therefore, not required Moreover, the scale division is more linear, so that the values of resistance may be read fairly accurately over the entire scale

Small or large resistance values cannot be measured accurately with either of these methods A Wheatstone bridge or a comparison method must be used for these

Component testing with an ohmmeter

Most ohmmeters may be used for testing semiconductors, provided that the potential at the test terminals is sufficiently high A diode has a very large resistance when the test leads are connected across it in one way and a much smaller one, depending on the type of diode when the test leads are reversed. In the first case, the diode is reverse-biased and in the other forward-biased The forward-bias resistance of point-contact diodes is considerably higher than that of junction diodes. Measurements of this nature indicate only whether the diode is functional or defect: other than that. they do not show how the diode will behave in a circuit.

Testing of transistors must be done in six stages—see Fig. 27. The resistance between emitter and collector is high in both directions That between base and collector or emit-

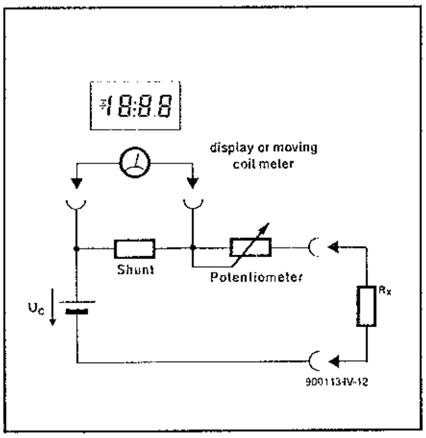


Fig. 25. Basic circuit for constant-voltage measurements

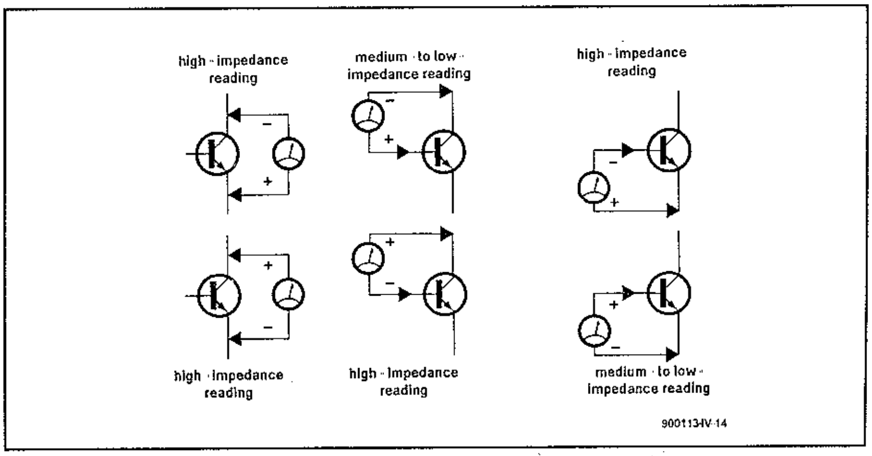


Fig 27 Testing a transistor with an ohmmeter requires six measurements.

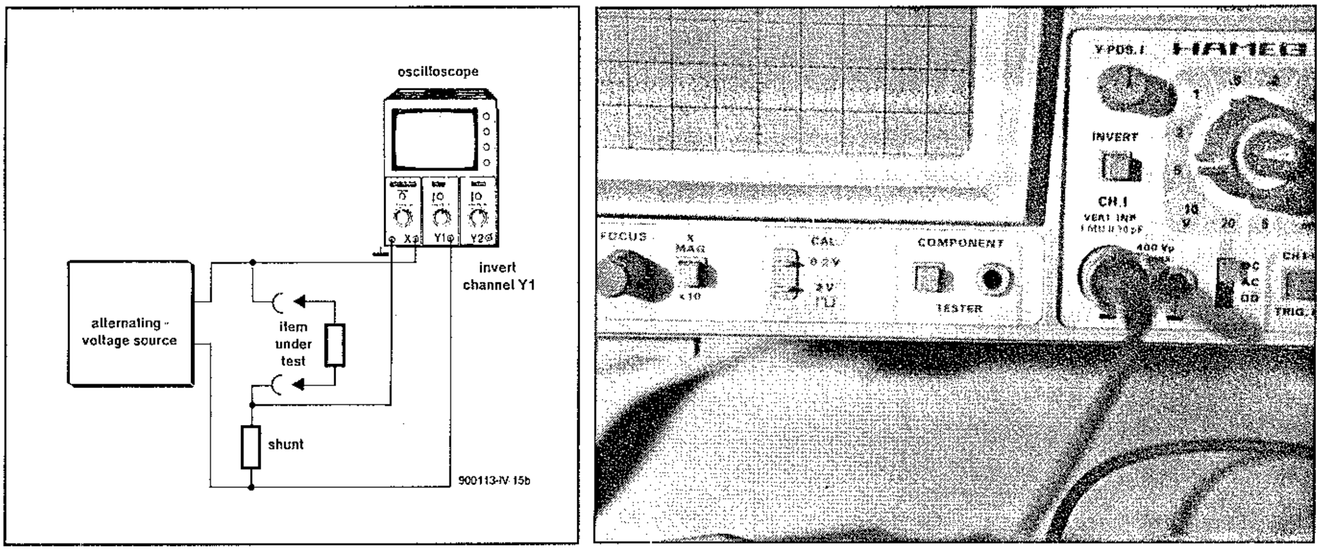


Fig. 28. Component tester: (left) test set-up and (right) incorporated in an oscilloscope.

ter is small in one direction and large in the other. The measured values depend on the applied voltage and current, as well as on the ambient temperature. It is thus not possible to measure absolute values, but short-circuits and open-circuits are, of course, indicated. When transistors are tested in-circuit in this manner, the effect of surrounding components must, of course, be taken into account. For more accurate measurements, the transistor should be removed from the circuit.

Component tester

On the basis of the foregoing, special component testers for use with, or incorporation in, oscilloscopes have been developed as shown in Fig. 28. The basic circuit of the tester is fairly simple: a low alternating voltage, drawn for instance from a mains transformer, is used as the supply for the series network of component under test and shunt resistor. The alternating voltage is used as the horizontal time-base, while the potential drop across the shunt resistor is used for the vertical deflection of the electron beam. When the component tester is in use, the internal time-base of the oscilloscope is, of course, switched off.

The voltage drop across the shunt resistor determines the current through the component under test. The screen of the oscilloscope shows the *IU* characteristic (*U* in horitonzal direction) and thus the resistance curve of the component under test. No reference is provided, so that the trace only shows the relative resistance of the component under test.

Since the component tester is so simple, it is possible to use it with, or build it into, any oscilloscope whose time-base can be switched off and which has an additional X-input available.

Note that since the earth potential must be at the centre between component under test and shunt resistor, the current trace is inverted. In a number of oscilloscopes, the Y-channel can, however, be inverted, so that

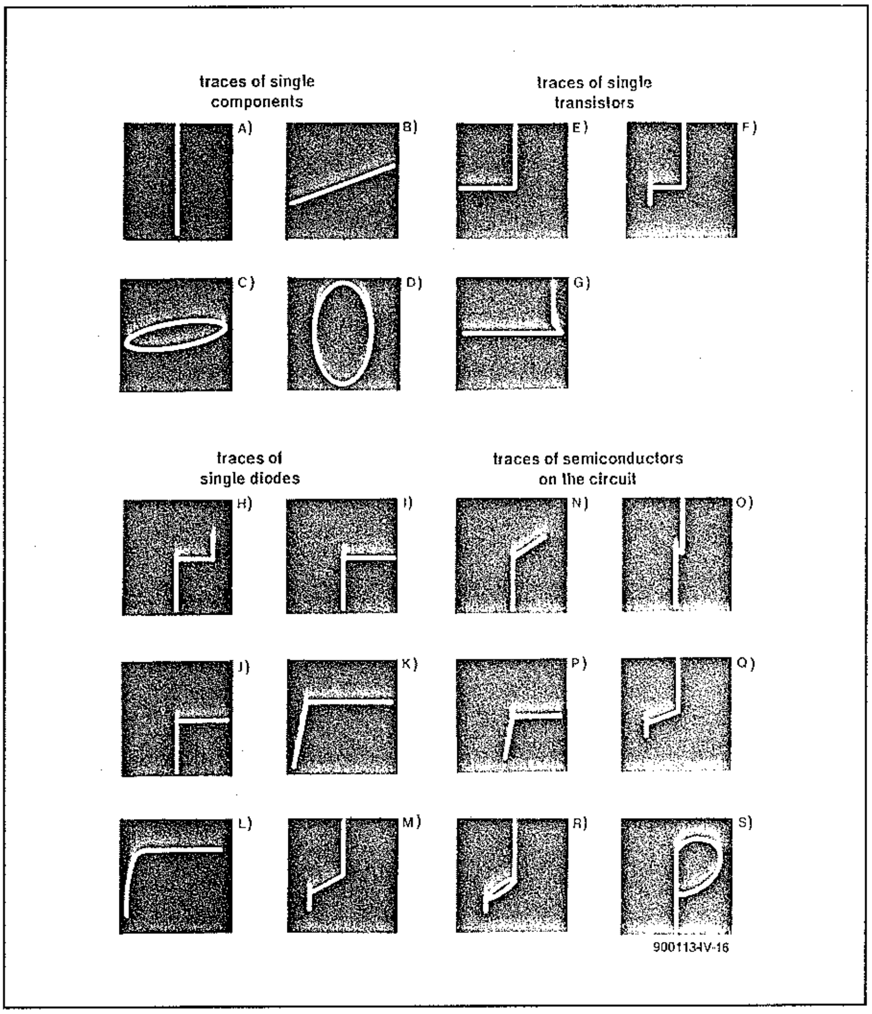


Fig. 29. Traces obtained from measurements with a component tester: A) test terminals short-circuited; B) true resistance; C) inductor; D) capacitor; E) base-collector junction of a transistor; F) base-emitter junction of a transistor; G) emitter-collector junction of a transistor; H) zener diode whose zener voltage is lower than the maximum test voltage; I) zener diode whose zener voltage is higher than the maximum test voltage; J) silicon diode; K) germanium diode; L) rectifier; M) thyristor whose gate is connected to its anode; N) parallel network of diode and resistor; O) two diodes connected in anti-parallel; P) series network of diode and resistor; Q) resistor in parallel with the base-emitter junction of a transistor; R) parallel network of resistor, capacitor and base-emitter junction of a transistor; S) diode and capacitor connected in parallel

a correct trace is obtained

There must be no voltage across the circuit or component under test, otherwise the measurement becomes meaningless

Correctly interpreting the trace requires some practice particularly when the measurement is carried out on a circuit

If the component under test is a true resistance, there is no phase shift between the two deflection voltages and the trace is a straight line The tilt of the line is a measure of the resistance: when this is 0 the trace is upright when it is ∞, the trace is horizontal

Measurement of impedance

The component tester may also be used to determine impedance values Capacitors and inductors cause a phase shift between the voltage across and the current through them, and thus between the deflection voltages This gives rise to elliptical traces, the height and width of which are typical of the impedance of the component under test—see Fig 29 Exact measurements are possible only if the relation between the horizontal and vertical deflection voltages is known. The vertical deflection is calibrated on all oscilloscopes When the set value is divided by the value of the shunt resistance the deflection on the screen is in A/div or mA/div. The X-deflection is often not calibrated. but the voltage at the relevant input may be measured fairly easily by switching off the time base and setting the trace exactly in the centre of the screen Then deflect the trace to the nearest graticule division by applying a voltage to the X-input. The level of that voltage gives the value V/div Once this has been determined, the values of voltage and current can be read directly from the traced characteristic

Impedances may of course also be measured without the use of an oscilliscope and component tester A sine-wave generator and an instrument that can process frequencies are then required The component under test is connected to the generator after which the voltage across it and the current through it may be measured. The impedance Z, is determined from the relation $Z = U / I$ The true resistance must be deducted from the obtained value to arrive at the value of the reactance, X In view of the phase shifts. however, this must be done geometrically, that is. $X^2 = Z^2 - R^2$. The values of reactance and impedance are valid only at the frequency of the test signal

The reactance X_L, of an inductor is

$$X_L = \omega L = 2\pi f L,$$

whence,

$$L = X_L / 2\pi f.$$

The reactance and value of a capacitor are calculated in a similar manner

$$X_C = 1 / \omega C,$$

and

$$C = 1 / \omega X_C = 1 / 2\pi f X_C$$

Measuring the supply voltage

One of the most frequent measurements is checking the supply voltage of an equipment. Moreover, preliminary tests in design and development aim at deciding whether a given voltage- or current-source is suitable for the project in hand. Most supplies can be checked with three or four measurements of: e m.f.; short-circuit current; internal resistance R_i; and, in the case of a d c source, the hum voltage. U_h Most voltage sources provide a direct voltage or an alternating voltage with a frequency of 50 Hz. Both of these may be measured with a multimeter without any problem

To measure the e m f , it is imperative that the source is not loaded: if the output impedance of the source is not particularly high, the input resistance of the multimeter may be ignored

Measuring the short-circuit current is in many cases not recommended It is better to determine the internal resistance, which in most cases will enable the short-circuit current to be calculated

Measuring the internal resistance of a home-made regulated supply can be very revealing: for one thing. it shows how good the supply really is A pretty good and simple way of determining R_i is possible with the circuit shown in Fig 30 The source is loaded with a variable resistor that is set to a position where exactly half the e m.f is dropped across it The drop across R_i must then be the same, which means that the internal resistance must have the same value as that presented by the variable resistance Note that this method is not suitable when the value of R_i is relatively high, because the current may then become relatively large. The method is however suitable for determining the input and output resistance of an electronic circuit

The simplest way of determining the internal resistance of a voltage source is as follows and requires knowing two operating points The first of these may be the e.m f , U_o The second may be determined by loading the source with a resistance, R_l, whose value must cause the output voltage to be appreciably lower than the e.m.f The internal resistance is then calculated from:

$$R_i = (U_o - U_l) / (U_l / R_l) = R_l (U_o - U_l) / U_l$$

If for example the e m f of an a c source is 25.2 V and the output voltage drops to 23 5 V when a load of 5.6 Ω is connected across the output the value of the internal resistance is:

$$R_i = 5\ 6\ (25\ 2 - 23\ 5) / 23\ 5 = 0\ 41\ \Omega$$

Note that the output current is then 4 2 A: this value must be lower than the maximum output current before current limiting sets in. As soon as current limiting takes place, the internal resistance rises rapidly. which invalidates the measurement

Compensating method of measurement

The smaller the internal resistance of a voltage source the better regulated the output voltage Electronically stabilized power supply units have a very small internal resistance, provided the maximum output current is not exceeded. Such small resistances cannot be measured by the methods described so far at least not with any degree of accuracy. They can be measured accurately by the so-called compensating method. which requires some care in calibration however

The test set-up is shown in Fig. 31. The unit under test is loaded by a variable resistance R_l, and the resulting current, I_l, is measured The voltmeter indicates the difference, U_d between the potential across R_l and the compensating voltage U_{ref}, which is set by R_2 This resistance is varied until $U_d = 0$ At the same time lower and lower ranges of tthe voltmeter are selected to make the calibration as accurate as possible Then, R_i is

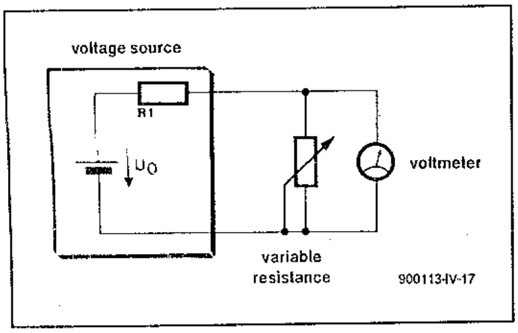


Fig. 30 A pretty good and simple way of measuring the internal resistance of a voltage source

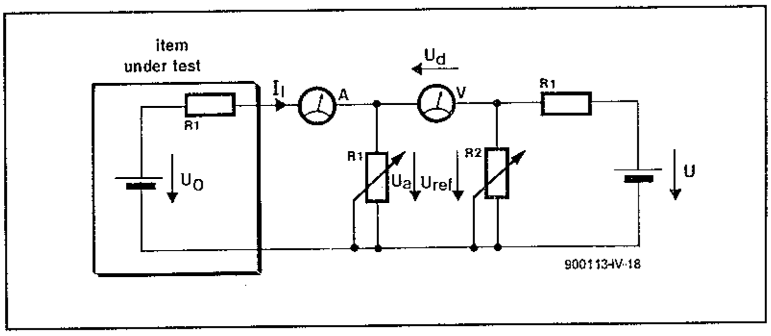


Fig 31 Compensating method of measuring small internal resistances.

carefully varied in small steps This will cause a change in I_1 as well as in U_o as indicated by the two meters. The internal resistance is calculated by dividing the change in output voltage by the change in current

Measuring hum voltage

All d c supplies derived from an alternating voltage retain a certain amount of a c however small superimposed on the direct voltage output This a c. component manifests itself as hum The lower the hum level. the better the power supply at least in this respect The a.c. component can be measured by removing the d c with the aid of a capacitor On oscilloscopes this is done by setting the input selector (AC/GND/DC) to AC The a.c. component may then be displayed on the screen with very good resolution Since the hum voltage is seldom sinusoidal it is normally specificed as peak-to-peak. and this is clearly seen on the screen.

Multimeters set to a c ranges also isolate the d.c voltage from the input signal so that only the a c component is measured Since this component is normally not sinusoidal the indicated value is only reliable if a true-r m.s multimeter is used

(to be continued)

DECADIC VOLTAGE DIVIDERS

by Ing. G. Peltz

Designing decadic voltage dividers is not as simple as it may seem. One decade is not too difficult, but when a number of decade steps are to be selected by a rotary switch the design becomes rather more tricky. Or does it? In this article, an old divider circuit is rehashed that otherwise may easily be overlooked in these days of microprocessor-controlled digital potentiometers.

FIGURE 1 shows the basic circuit of a 3-decade voltage divider. Switches S_1 and S_2 are 2-pole 10-position types, while S_3 is a single-pole. 11 position type. Both S_1 and S_2 select two resistors at a time from a divider chain. The value of the parallel combination of these two resistors and the following chain is equal to that of a single resistor This requirement is fulfilled when for example chain 1 contains resistors of value R, chain 2 contains resistors of value $R/5$. and chain 3 contains resistors of value $R/25$. Note that S_1 and S_2 are always displaced two positions with respect to each other

Since the value of the parallel combination of the two resistors between the poles of S_1 and the following chain is equal to that of a single resistor in the first chain the voltage drop across each resistor is the same as the potential between the two poles of S_1 that is. the input voltage U_r divided by 10 Similarly. the potential across each of the resistors in the second chain is $U_r / 100$. and that across each of the resistors in the third chain is $U_r / 1000$ This means that the output voltage (with respect to earth) may be selected in steps of a thousandth of U_r, depending. of course. on the tolerance of the resistors. which in this case must be 0 1%

Figure 2 shows a practical application of the foregoing: two resistor chains and a potentiometer provide an accurate variable voltage source Potentiometer P_3 may be replaced by a third chain of 47 Ω resistors

A temperature-compensated zener diode provides a very stable reference voltage U_r of 6 8 V from the supply voltage U_b

The values of the two resistor chains may

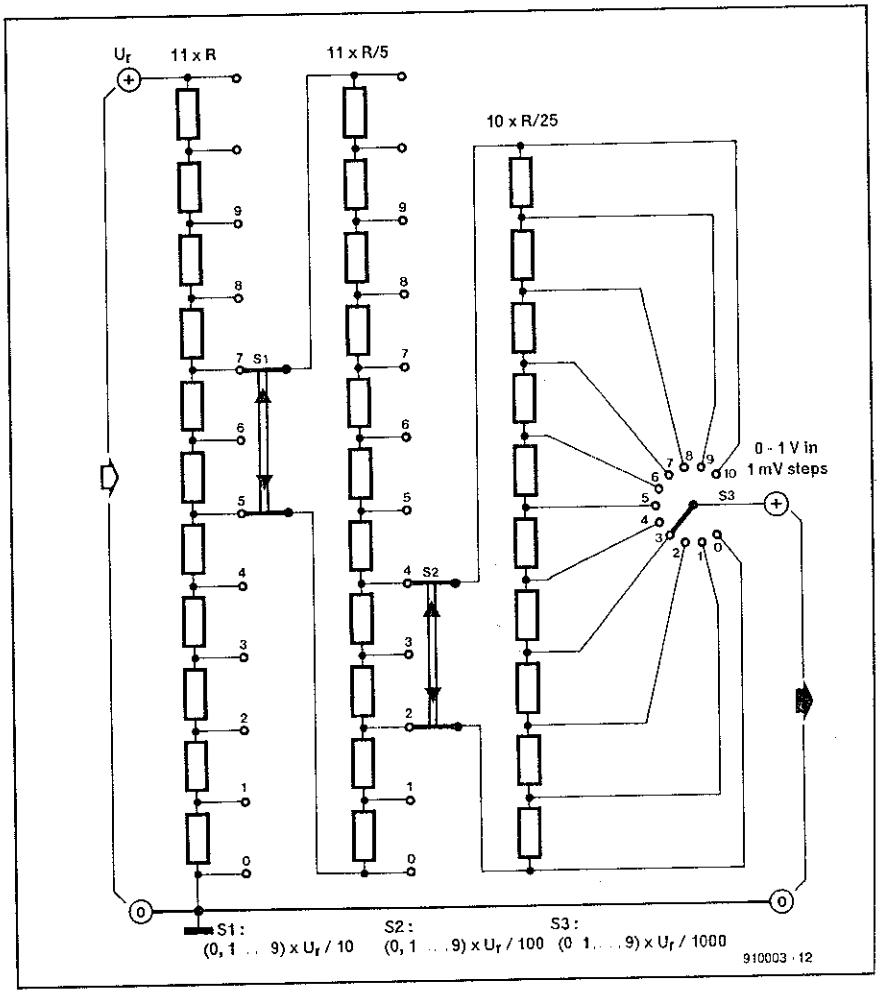


Fig 1 Basic design of a decadic voltage divider

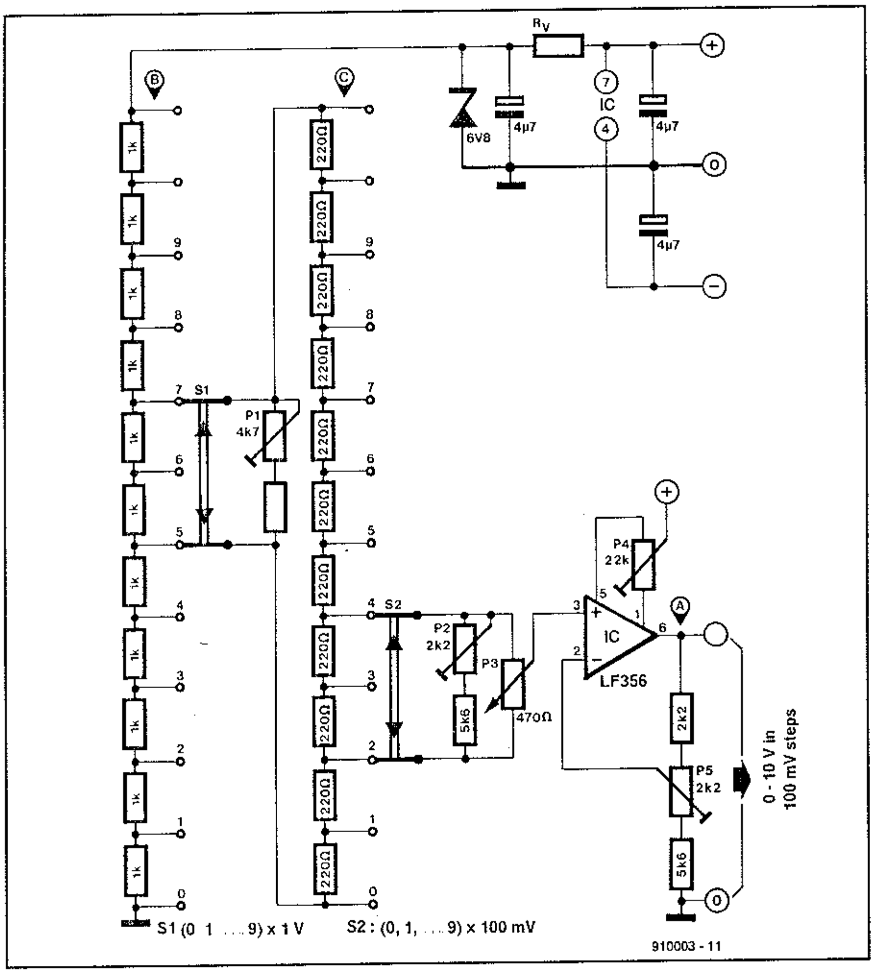


Fig. 2. Voltage source providing 0–10 V in 100 mV steps.

be adjusted by presets P_1 and P_2 respectively to give the second chain a total resistance of exactly 2 kΩ and "the third" that is, P_3, a value of 4 kΩ. If 2% resistors (of the same batch) are used in the dividers, an overall accuracy of 0.5% is obtained. This accuracy will, of course, be even better if 1% or 0.5% resistors (from the same batch) are used.

The potential at the wiper of P_3 covers a range of only 0–6.8 V and must not be loaded too heavily to avoid unacceptable errors. For that reason, the potential is applied to an opamp with FET inputs, which gives an output voltage range of 0–10 V preset by P_5.

The opamp is powered by an asymmetric voltage source: $+U_b = 12–18$ V; $-U_b = 5–10$ V.

Series resistor R_v in the positive supply rail has a value between 1 kΩ and 2.2 kΩ depending on the level of the supply voltage; it carries a current of about 5 mA.

Except for R_v, all resistors should be metal film types with a temperature coefficient, T_k, not greater than ±50 p.p.m. and a tolerance of ±1% or better. Presets P_1, P_2, P_4 and P_5 are multiturn cermet types, while P_3 is a good-quality wirewound type or a 47 Ω resistor chain as in Fig. 1. The switches should also be high-quality types.

Calibration

For calibration, a digital multimeter with a 4 $^1/_2$ digit display is required. Set all presets to the centre of their travel, and P_3 and the switches to their lowest position.

Turn P_4 until the output voltage is 0 V with respect to earth.

Check that the level at B is exactly the same as the zener voltage.

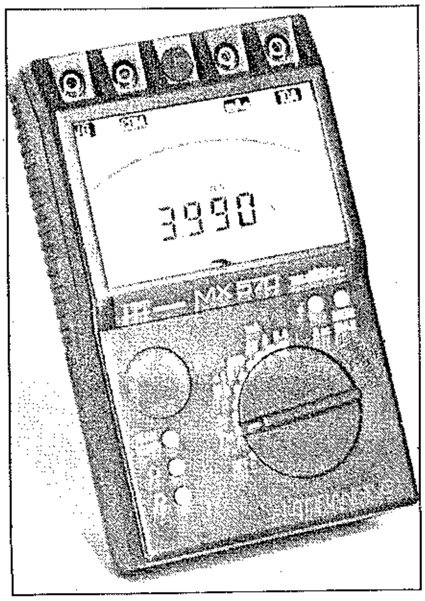
Turn P_1 until the potential at C is exactly one tenth of the voltage at B.

Set S_1 to position 1, i.e., between terminals 1 and 3, and turn P_5 until a voltage of exactly 1.000 V is obtained at the output.

Adjust P_3 for maximum output and then turn P_2 to give an output of 1.100 V.

Reset S_1 to position 0: the output should then be exactly 100 mV.

Since the controls affect one another slightly, the calibration needs to be repeated a couple of times. ■



NEW DIGITAL/ANALOGUE MULTIMETER FROM ITT

THE new Type MX570 from ITT Instruments is a combined analogue/digital multimeter that offers auto-ranging on both the traditional analogue pointer and the digital LCD read-out.

The instrument is aimed at traditional multimeter users who appreciate the accuracy and unambiguity of a digital read-out, but who find that alternative analogue solutions on simple bar-graph displays lack the same response and 'feel' of a true analogue pointer.

Both the analogue and digital displays of the MX750 share the same auto/manual ranging and auto-polarity electronics, and yet the pointer response is not restricted by the sampling rate of the analogue-to-digital converter.

ITT products are manufactured at a number of locations world-wide and are available in most countries. ■

NEW WAVEFORM GENERATOR FROM GOULD ELECTRONICS

GOULD has introduced the DWG-7000 digital waveform generator that covers the frequency range 10 µHz–10 MHz, and can produce both standard and arbitrary waveforms with a resolution of 100 ns per point. Internal memory is sufficient to store 8192 digital points. The vertical resolution is 12 bits.

Built-in standard functions include sine, square, triangle, d.c., positive ramp, negative ramp, positive pulse and negative pulse. All can be selected from the front panel or from a remote controller via IEEE-488 or RS 232 interfaces. A full complement of sweep functions is also available.

The DWG-7000 is suitable for all general purpose electronics applications.

Gould Electronics manufactures a wide range of electronic instruments, which are available in most countries of the world. ■