the same time solve the equation which represents the system. Sometimes the computer will be used just for solving equations or, alternatively, as a working model only, depending on the nature of the problem. The advantage of the electronic computer is that it will do each, or both at the same time, with ease.

The computer is set up, or "programmed", for a particular task by inserting computing components, i.e. resistors and capacitors, into sockets on the front panel. This procedure will be described in full detail in due course.

ANALOGUE COMPUTER CIRCUITS

In the electronic analogue computer, the analogy is created fundamentally by manipulating sets of d.c. voltages. There is nothing to prevent a.c. voltages being used—in fact they often are—except that a.c. measurement techniques are generally less accurate at low levels than d.c. However, when simulating dynamic processes with d.c. voltages, the computer will be handling a voltage which varies with time. In this context it is more appropriate to regard a waveform, even if it is a pure sinewave, as a d.c. voltage varying with time according to a formula which describes the nature of the waveform.

The main computing element is the "operational amplifier". As far as operational amplifiers are concerned, the decibel is much too coarse a unit to use for the measurement of frequency response, so amplitude linearity is usually expressed as a percentage variation over a fairly restricted range of audio frequencies. In some cases, for example, an operational amplifier and its attendant circuits will be expected to respond to inputs from d.c. to 5kHz with an accuracy of a fraction of 1 per cent, and up to 10kHz at no worse than 1 per cent.

COMPUTING ELEMENTS

The majority of problems can be solved by the varied application of only five analogue elements, but the size of the problem to be handled will in turn depend on the quantity of elements available, and hence on the overall size of the computer.

The five computing elements are shown in Fig. 1.2, together with their conventional symbols and generalised functions. The symbols are used as a kind of shorthand when drawing up a computer programme.

The first thing to note about the simplified circuit diagrams of Fig. 1.2 is that the common earth return is often completely ignored. Computer supply voltages are usually positive and negative in relation to an earthed centre tap. Since the input and output terminals of each

computing element are arranged to be very close to earth potential in the absence of an input voltage, it is feasible to take the earth rail for granted and regard all circuits as having only two terminals, instead of the usual four.

Although the symbol and function of each of the elements of Fig. 1.2 are common to all analogue computers, the actual circuit design and choice of components will naturally vary from one computer to another. For example, the time-division multiplier of Fig. 1.2e is only one among many possible circuit configurations for achieving multiplication of independent variables. Alternative approaches include the Hall effect, the servo, logarithmic, and quarter square multipliers.

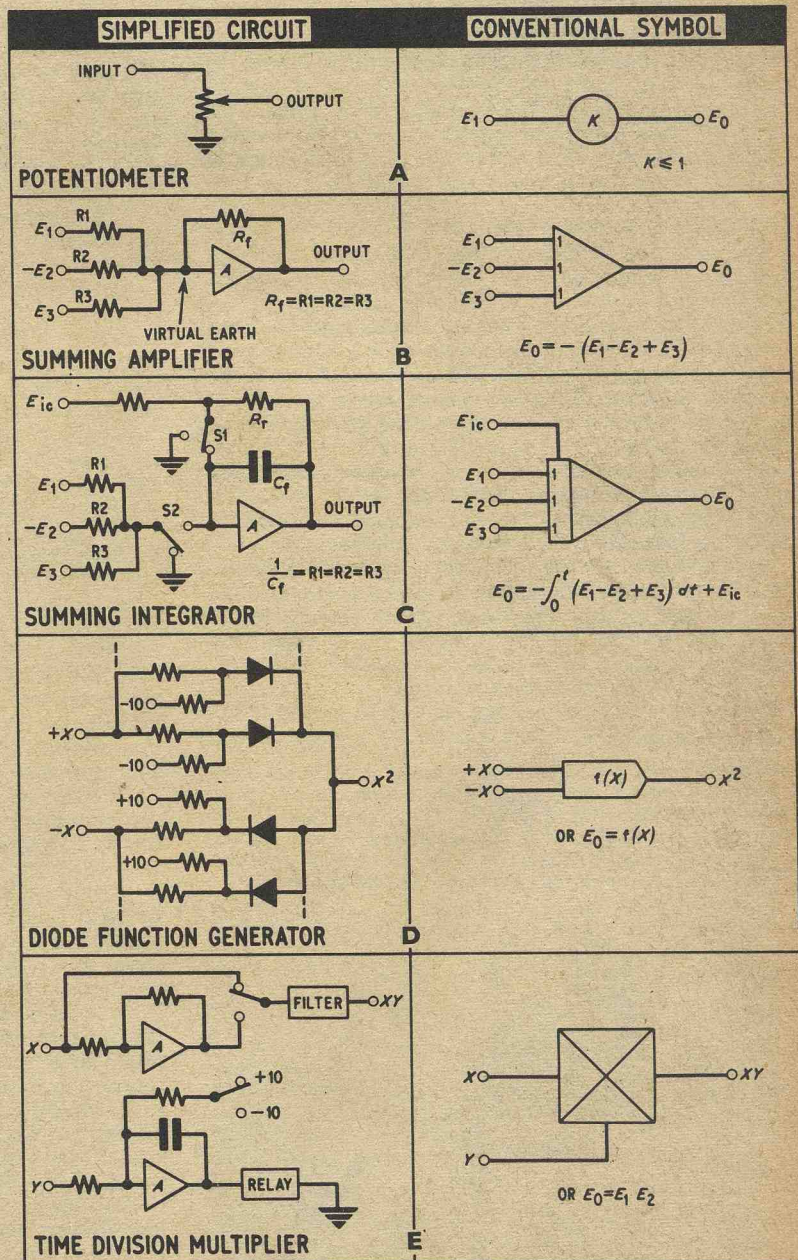| SIMPLIFIED CIRCUIT	CONVENTIONAL SYMBOL
POTENTIOMETER — A	E_1 — K — E_0 $K \leqslant 1$
SUMMING AMPLIFIER ($R_f = R1 = R2 = R3$) VIRTUAL EARTH — B	$E_0 = -(E_1 - E_2 + E_3)$
SUMMING INTEGRATOR ($\frac{1}{C_f} = R1 = R2 = R3$) — C	$E_0 = -\int_0^t (E_1 - E_2 + E_3)\,dt + E_{ic}$
DIODE FUNCTION GENERATOR — D	$+x$, $-x$ — $f(x)$ — x^2 OR $E_0 = f(x)$
TIME DIVISION MULTIPLIER — E	x, y — xy OR $E_0 = E_1 E_2$

Fig. 1.2 Analogue computing elements