It is proposed to examine computing elements in greater detail when they are dealt with individually at a later stage, but in the meantime a brief survey will suffice.

COMPUTING POTENTIOMETER

The potentiometer of Fig. 1.2a may be used for multiplying a variable voltage (often called a machine variable) by a constant of less than unity.

Example: potentiometer input 1·5 volts. Slider set exactly half way along resistance track, corresponding to a constant of 0·5. Output voltage E_o therefore equals $1{\cdot}5 \times 0{\cdot}5$, or 0·75. As set, the potentiometer will multiply any input voltage by 0·5.

When incorporated in the feedback loop of an operational amplifier, the potentiometer will divide a machine variable by a constant smaller than 1. The fact that potentiometer constants are less than unity is no real disadvantage. It is a simple matter to either increase input voltages by a factor of ten, or increase the gain of an operational amplifier ten times, to bring the potentiometer constant above unity. Like the slide-rule, it is simply a matter of deciding in advance where the decimal point should be.

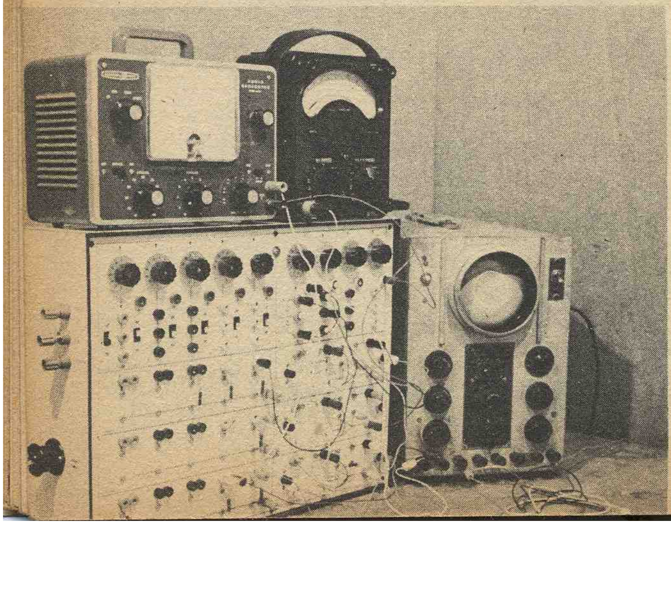
SUMMING AMPLIFIER

The summing amplifier of Fig. 1·2b uses a high gain operational amplifier with several inputs to achieve addition and subtraction of machine variables. When the operational amplifier has a voltage gain equal to several thousand, input voltages will be accurately summed together, without unwanted interaction. The summing junction SJ is at "virtual earth", a way of saying that SJ will never be more than a few millivolts above or below earth potential, and is also, to all intents and purposes, shunted by a resistance of only a few ohms. Compared with input resistors R1–R3, the SJ shunt resistance is very low indeed, a condition necessary for accurate summing of voltages.

A definite relationship exists between resistors R1–R3, and feedback resistor R_f, and if these resistors are arranged to plug into the amplifier, many problem conditions can be met by "ringing the changes" on preferred values of fixed resistor, including multiplication by a constant as well as addition.

If a voltage E_1 is applied via resistor R_1 (in Fig. 1.2b) ot the summing junction SJ, the output voltage E_o will

This photograph shows UNIT "A" being used to simulate a tuned LC circuit, consisting of an inductance of 5H in series with a capacitance of 5µF. The oscilloscope is displaying phase shift within the simulated circuit at the resonant frequency of 31Hz, and the trace also gives an indication of the damping factor or "Q" of the circuit



be $-\,E_1 \dfrac{R_f}{R_1}$. The operational amplifier is designed to invert an input voltage, hence the minus sign in front of this expression. The ratio between input resistor and R_f holds good for each input.

Example: apply three input voltages $E_1 = 5$, $E_2 = -\,3{\cdot}5$, and $E_3 = 2$ to the summing junction via $R_1 = 10$ kilohm, $R_2 = 2$ kilohm and $R_3 = 100$ kilohm. Let the feedback resistor $R_f = 10$ kilohm. The relationship between voltages and resistances will be

$$E_o = -\left(E_1\frac{R_f}{R_1} - E_2\frac{R_f}{R_2} + E_3\frac{R_f}{R_3}\cdot\right) \text{ Substituting values}$$

$$E_o = \left(5\frac{10}{10} - 3{\cdot}5\frac{10}{2} + 2\frac{10}{100}\right) = (5 - 3{\cdot}5 \times 5) + 0{\cdot}2),$$

therefore $E_o = 12{\cdot}3$.

In the above example, the summing amplifier has not only summed negative and positive inputs, but has also multiplied E_2 by 5, and E_3 by a constant of 0·1, merely by selection of appropriate values of input resistor.

SUMMING INTEGRATOR

The summing integrator is used for the detailed investigation of time dependent variables, and for the solution of problems involving calculus.

The integrator of Fig. 1.2c is based on the inverting operational amplifier, with capacitor C_f acting as the feedback component. The output from a single integrator, in response to a steady voltage input, is a linear ramp voltage which increases with time at a rate dependent on choice of input resistor, feedback capacitor, and input voltage. Once again, precise relationships must exist between computing components and voltage, but now time is introduced as an additional analogue variable.

The action of electronic integration is best explained by a working example, and reference should be made to the diagram of Fig. 1.3a.

Example: a fairly sluggish motor car accelerates from rest at a steady rate of 20ft/second/second. Examine the progress of the motor car during the first four seconds of its motion. The computer is set up to operate in "real time", that is to say, the time actually occupied by the motor car when accelerating. The problem layout of Fig. 1.3a shows a computing potentiometer "A" coupled to the input of Integrator "1", which in turn feeds Integrator "2". Voltmeters are connected into circuit to display the three parameters of interest. Potentiometer "A" is first adjusted so that its dial reads 2, corresponding to multiplication by the constant 0·2, to represent 20ft/s^2 scaled down to yield a voltage of appropriate magnitude for the integrators to handle. The output from the potentiometer is a steady voltage analogue of a steady rate of acceleration.

As soon as switch S3 is closed to the +V position, the velocity and distance meter pointers will start to move in a manner analogous to the motion of the motor car. Velocity will increase linearly with respect to time, while distance will be displayed as an accelerating pointer movement. Integrator "2" computes distance (s) as a voltage function of the square of time, in terms of $s = \frac{1}{2}at^2$.

With the problem of Fig. 1.3a, acceleration, velocity, and distance are immediately available to the computer operator as dial and meter readings. He can vary acceleration just by turning the dial of the potentio-