We now consider the use of the multiplier UNIT "D" in solving equations.

THE MULTIPLIER IN EQUATION SOLVING

Fig. 10.1 sets out four multiplier configurations to show how equation terms may be handled. As a self-contained computing element, UNIT "D" will multiply input voltages X and Y to give a product $XY/10$, see Fig. 10.1a. Note that arrows are normally used with the multiplier symbol to identify input and output terminals.

Division of two variable voltages is achieved, in Fig. 10.1b, by placing the multiplier in the feedback loop of an operational amplifier. However, with division, certain limitations are imposed. The Y input must be of single polarity, which rules out a.c. waveforms unless they are d.c. biased above or below $Y = 0$, but ramp or step functions will be accepted if they do not change their sign. With the X input, voltages can be 0 to ± 10V d.c., or a.c. peak.

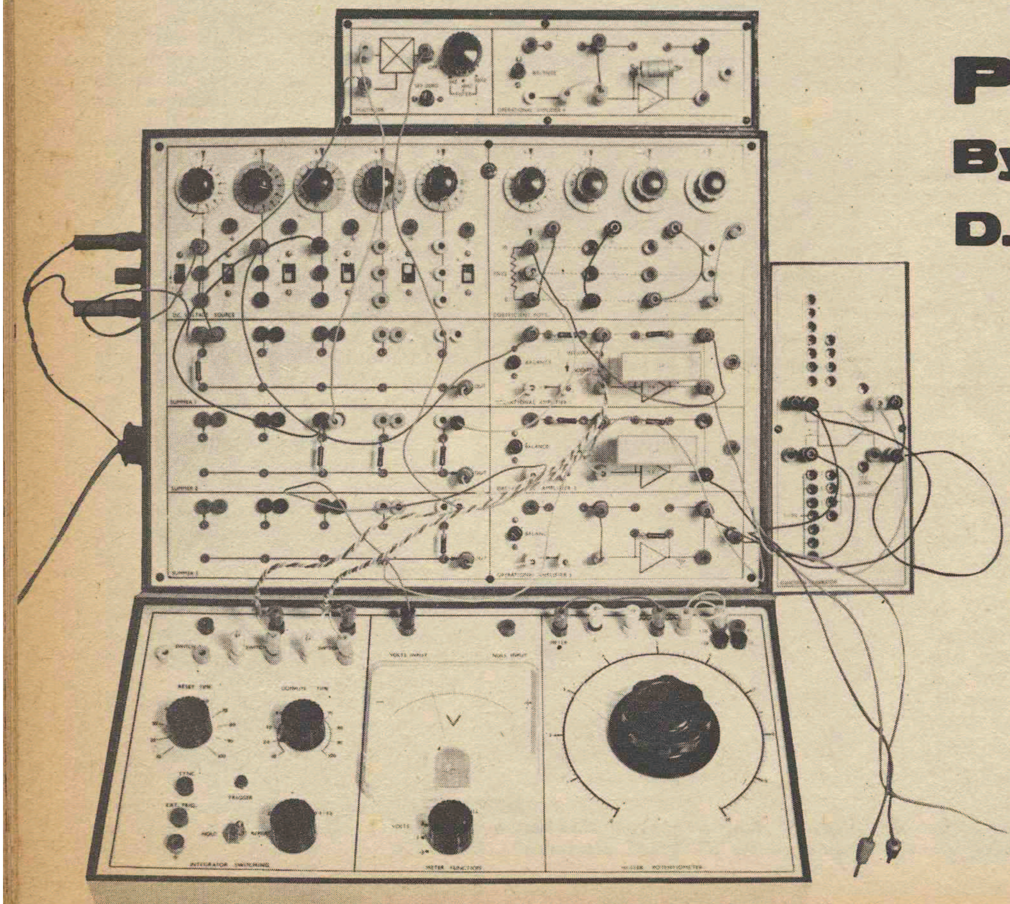
Because an extra filter capacitor (shown dotted in Fig. 10.1b) is needed to prevent amplification of low-level carrier ripple by the open-loop, high gain amplifier, frequency response is restricted to 10Hz for the division operation, when switch S11 is in the 50Hz position. It is sometimes possible to arrange a problem so that the reciprocal is multiplied, and thus avoid the limitations of Fig. 10.1b division. A related configuration in Fig. 10.1c gives an output $XY/(1 + X)$, for inputs of $\pm X$ and $\pm Y$.

In the final example of Fig. 10.1d, the multiplier is combined with integrators, and therefore handles time varying voltages. By solving the equation $\mathrm{d}A/\mathrm{d}t = 2\pi R \times \mathrm{d}R/\mathrm{d}t$, which describes the rate at which the area of a circle changes with a growth of radius, the layout of Fig. 10.1d can be used to investigate,

ANALOGUE COMPUTER

PE AC

By D. BOLLEN



The Practical Electronics Analogue Computer in its complete and comprehensive form. The whole of this equipment has been fully described in this series of articles which is concluded this month say, the build-up of tape on a spool, the expansion or contraction of metal discs and cylinders when heated, or the surface area of a liquid in a conical reservoir.

SPECIAL ANALOGUE COMPUTER CIRCUITS

Apart from the analogue computing elements already covered are a few specialised diode circuits which are used for simulating various mechanical phenomena. Ordinary silicon diodes, such as the OA202, can be employed with the circuits of Fig. 10.2, and are inserted into the computing component sockets of UNIT "A".

Dead Zone. Amplifier gain in Fig. 10.2a is zero until the limits

$$E_{in} = -\frac{R1}{RB_1} \times 10$$

or

$$E_{in} = \frac{R2}{RB_2} \times 10$$

are reached, thereafter gain will depend on the slope given by R_f/R1 and R_f/R2.

Limiter. In Fig. 10.2b, amplifier gain is constant between the limits set by

$$E_o = \frac{R1}{RB_1} \times 10$$

and

$$E_o = -\frac{R2}{RB_2} \times 10$$

When the limits are exceeded, the gain falls to zero.

Friction. A frictional force generated by moving surfaces in contact is virtually constant for all values of

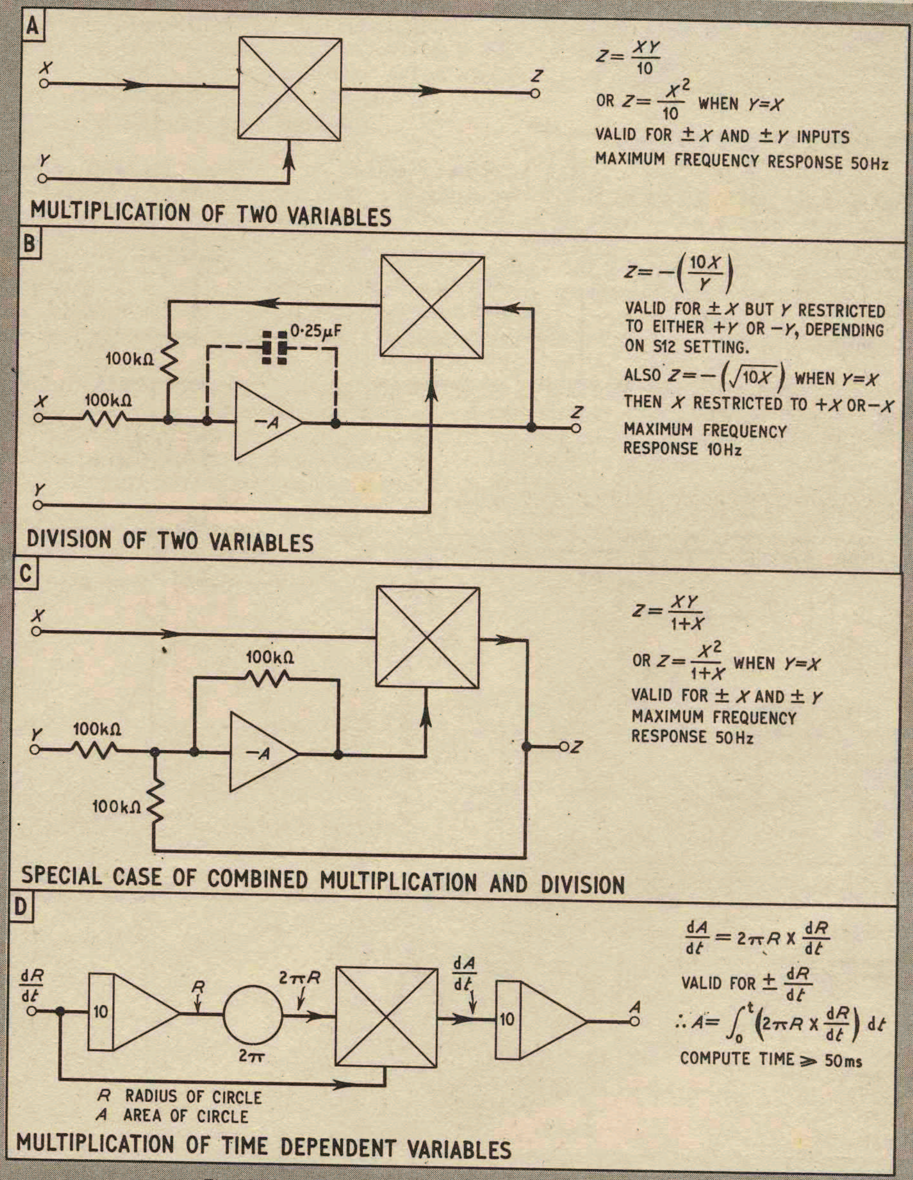


Fig. 10.1. The multiplier used for equation solving

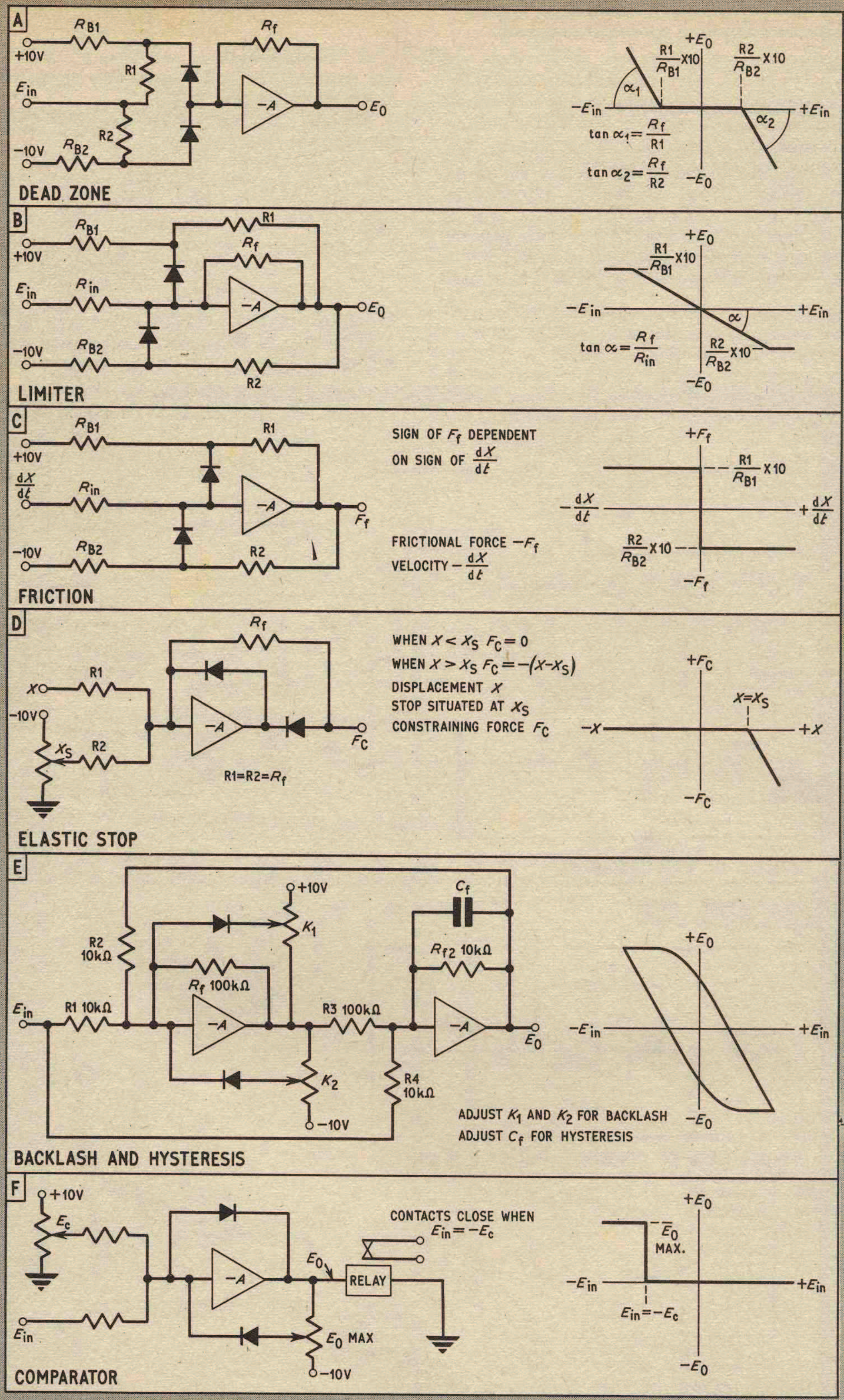


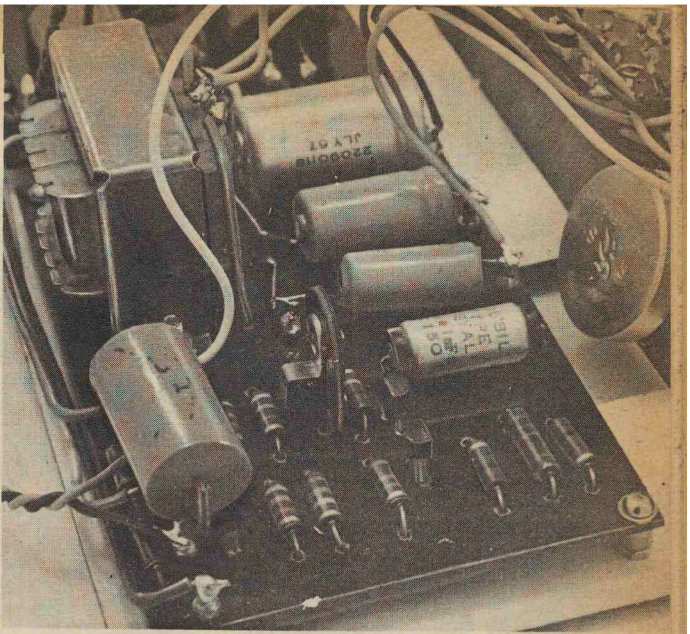
Fig. 10.2. Special circuits for simulating mechanical phenomena

velocity, but will change sign when the direction of the velocity is reversed. Circuit Fig. 10.2c satisfies the above conditions and generates a voltage proportional to a frictional force F_f.

Elastic stop. When an object makes contact with an elastic stop, the resulting constraining force is proportional to the penetration of the object into the stop. In Fig. 10.2d, term X_s represents the position of the elastic stop, while X is the displacement of the object. When $X \geqslant X_s$, the amplifier provides an output F_c which represents the constraining force.

Backlash and hysteresis. Mechanical linkages, gear trains, and some electrical circuits will often exhibit backlash and hysteresis, which are simulated by the circuit of Fig. 10.2e, using a dead zone and an integrator. Apart from K_1, K_2, and C_f, adjustments to R2, R3, and R4 will allow a wide range of characteristics.

Comparator. As its name suggests, the comparator of Fig. 10.2f compares one voltage with another, and enables some action to be taken at a pre-arranged input level. The comparator can be applied to the simulation of impact forces, where the constraining force is proportional to the *rate* of penetration; when $E_{in} = -E_c$, the relay contacts will close and insert a voltage representing velocity into an equation.



Product amplifier circuit panel

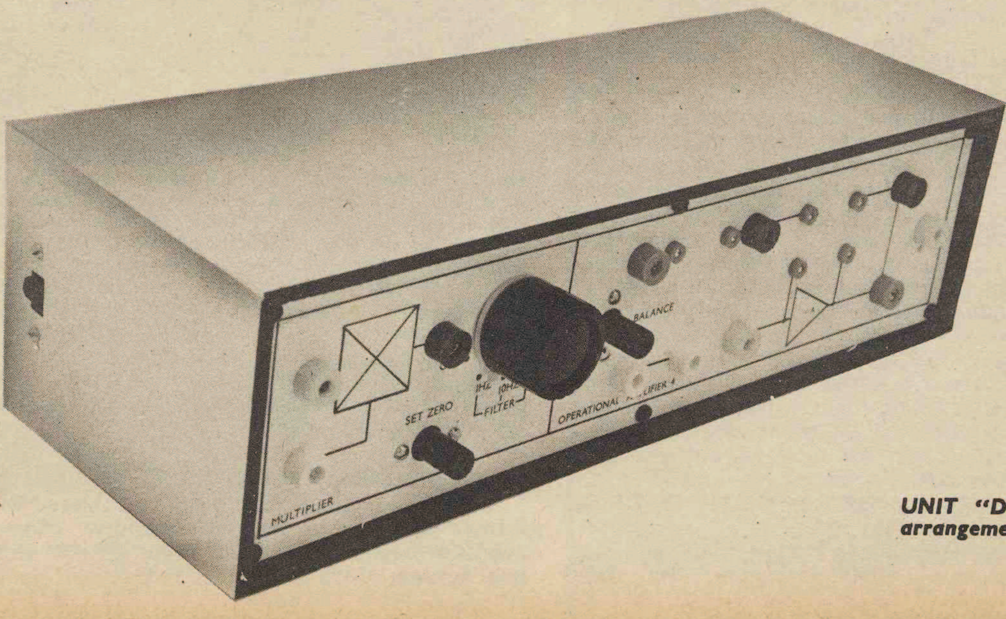
CONCLUDING NOTES

A brief mention should be made of those aspects of analogue computer usage which were considered to be beyond the scope of the present series. It would have been difficult to include the more complex Calculus problems which PEAC is capable of solving, and also transfer function techniques were avoided because they would have demanded some knowledge of Laplace transforms and the like.

A very important field is the use of analogue computers in controlling processes and evaluating data, so called "In-plant" applications, but here fairly elaborate sensing equipment and servomechanisms are called for, to act as intermediaries between the external process and the computer.

An important omission, brought to light by a reader's letter, concerns the use of a temporary feedback resistor when checking the coefficient of a potentiometer which is employed for division (Fig. 4.1f). If the feedback resistor is not present, the operational amplifier summing junction will no longer be at virtual earth when the potentiometer is disconnected for measurement purposes, and this can lead to serious errors. Therefore, when checking a division potentiometer coefficient, always insert a 10 kilohm feedback resistor into OA/SK11 and SK12.

If difficulty is experienced in zero-setting a UNIT "A" operational amplifier after construction, by adjustment of VR1 on the amplifier panel, it may be that transistor "spreads" are greater than has been allowed for in the design. The simple cure is to increase R1 (Fig. 3.7) to 4·7 megohm if the amplifier output is fixed close to the negative supply rail voltage, or, when the output remains clamped near to the positive rail, decrease R1 to 3·3 megohm. ★



UNIT "D" front panel arrangement and cabinet