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.

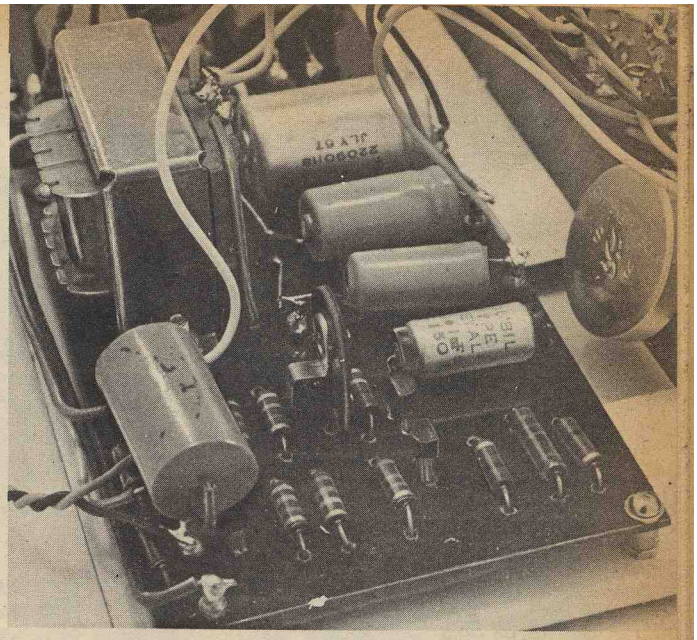
CONCLUDING NOTES

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.

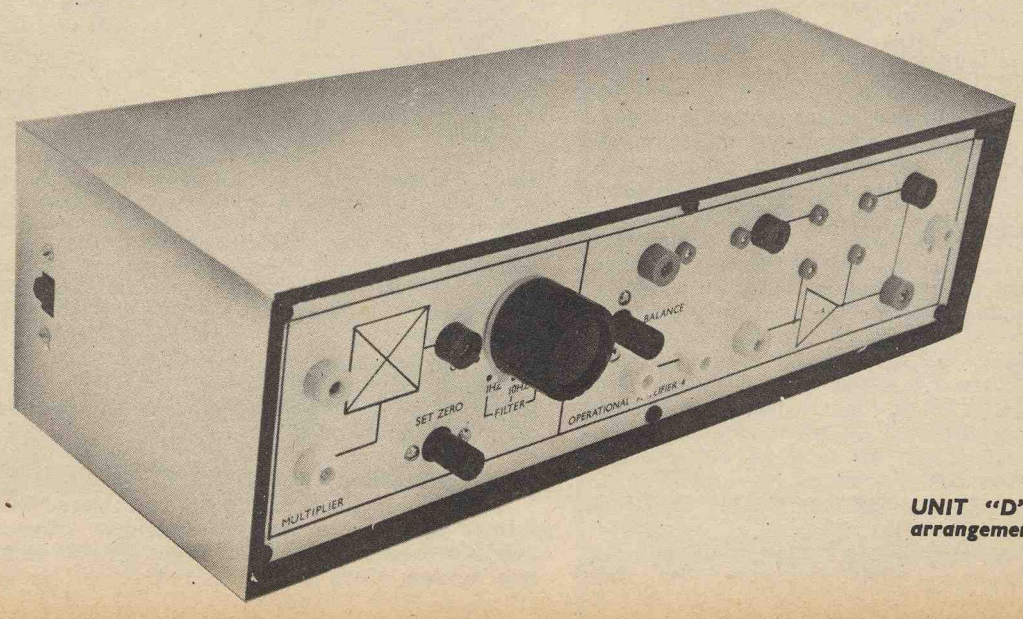
A very important field is the use of analogue computers in controlling processes and evaluating data, so called "In-plant" applications, but here fairly elaborate sensing equipment and servomechanisms are called for, to act as intermediaries between the external process and the computer.

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. ★



Product amplifier circuit panel



UNIT "D" front panel arrangement and cabinet