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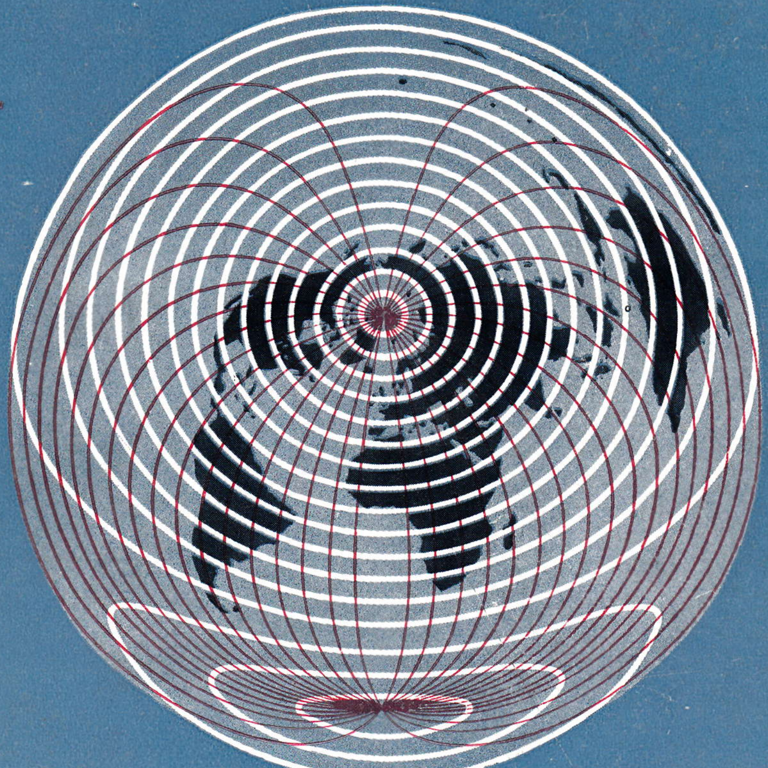
ELECTRONICS

Radio · Television



FIFTIETH YEAR OF PUBLICATION

r (shown schematically m), the sum of these nces, and thus the out- e, is kept constant by ch of the two divider out of a number of parallel and switching resistors from one arm l divider to the other to uation. (For example, R, may be switched to tted position.) This is switching conductances to the other and thus n of the two arm con- stant.

Coaxial Transistor of e, and a very wide band mplifier making use of developed at Bell Tele- atories. The transistor diffused-based, alloyed- ture and is designed for cillator at 3Gc/s, or as at 1Gc/s and below. only 1.8 mils long, and wide. Three metal ch 0.3 mil wide by 1.5 e evaporated on to the be plateau and alloyed conductor. Gold wires diameter are used for ections. The diffused 0.02 mil thick. Since encapsulating methods luce too much parasitic and inductance, the mounted in a coaxial electrically matches a line. The germanium d bonded to the inner the output section; the ipe" is connected to an eld integral with the shell; the base e connected to the centre f the input line. The mplifier, constructed on -line principles, has a B, flat within 1dB from /s to over 750Mc/s , with correspondingly dwidth, can also be In the amplifier the rthed in order to main- onductor continuity, and or biases are stabilized cal shunt feedback. A y transistor is inserted ng circuit to increase the d.c. without wasting amounts of high fre- . The amplifier is said ellent stability, and the measured at 200Mc/s th the feedback loop.

uctor Bullet-in.—An un- od of testing the shock- perties of semiconductor ed by the International rporation, has been ut of a shotgun into a directory. Apparently up to page 772 has been We are now waiting first grouse to be bagged action.

Simple Analogue Computer

INEXPENSIVE INSTRUMENT CONSTRUCTED FOR DEMONSTRATION PURPOSES

By G. B. CLAYTON,* B.Sc.

THE electronic analogue computer has in the last few years become an important tool for the engineer, physicist, and applied mathematician. While it is not capable of the accuracy of a digital computer it is nevertheless extremely useful for the analysis of many practical dynamical systems, its accuracy usually exceeding that of the known input data. Further, the analogue computer requires no specialist knowledge of computer programming techniques, an analysis of a physical system being carried out by setting up a direct electrical equivalent of the system. The physical variables of the system are represented by voltages which are made to vary in exactly the same way as the physical quantities. This method of analysis enables a greater insight of the dynamical behaviour of the system to be acquired.

The most important components of an electronic analogue computer are d.c. amplifiers, which are made to sum and integrate by the connection of suitable feedback and input impedances. A good many analogue computers are commercially available, ranging from desk-top instruments, using only a small number of amplifiers, to large complex installations using over a hundred amplifiers.

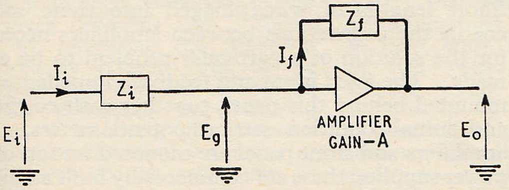


Fig. 1. Basis of the operational amplifier used in the analogue computer.

The author required a small computer suitable for introducing students to computer techniques and for demonstrating some of the many computer applications. Accuracy of solution was not of primary importance and it was therefore felt that the purchase of a commercial instrument was uneconomical. By simplification and the use of "surplus" components it has been found possible to build a small computer that performs very satisfactorily at a small fraction of the cost of a comparable commercial instrument. This article will first outline the basic theory of electronic analogue computers and will then describe the equipment constructed. A subsequent article will give an example of its use.

The Operational Amplifier.—Consider an amplifier whose gain $-A$ extends down to zero frequency and whose output terminal is arranged to be at earth potential when its input terminal is earthed. The negative sign indicates that the amplifier is phase reversing, i.e. if its input terminal were made x volts positive with respect to earth its output terminal would become Ax volts negative with respect to earth. Let a feedback impedance Z_f and an input impedance Z_i be connected as shown in Fig. 1, and assume the amplifier draws no current at its input grid and that its output impedance is negligibly small compared with Z_f and Z_i. If the gain of the amplifier is very large its input will differ very little from earth potential even when it is giving its maximum output. As an approximation the input grid may be thought of as always being at earth potential, and using this approximation one has

$$I_i = \frac{E_i}{Z_i} \quad \text{and } I_f = -\frac{E_o}{Z_f}$$

But the amplifier draws no current at its input grid, and therefore $I_i = I_f$.

This gives $E_o = -\dfrac{Z_f}{Z_i} . E_i$ .. .. .. (1)

If the impedances are made equal resistances, $Z_f = Z_i = R = 1\ M\Omega$, say, then $E_o = -E_i$ and the amplifier acts as a sign changer, or more generally with unequal resistances $E_o = -\dfrac{R_f}{R_i} . E_i$, and the amplifier multiplies by the constant coefficient $-\dfrac{R_f}{R_i}$.

Normally R_f is held constant at $1\ M\Omega$ and R_i is changed when necessary. If the input impedance is made a resistor and the feedback impedance a capacitor then $Z_i = R_i$ and $Z_f = \dfrac{1}{j\omega C} = \dfrac{1}{P.C}$

P is the differential operator $\dfrac{d.}{dt}$ and we use the equality $j\omega = P = \dfrac{d.}{dt}$ which is quite common in electrical engineering. Substitution in equation (1) gives:

$$E_o = -\frac{1}{CR_i} \cdot \frac{1}{P} \cdot E_i = -\frac{1}{CR_i} \int_0^t E_i dt$$

The amplifier integrates and multiplies by $-\dfrac{1}{CR_i}$.

With $C = 1\mu F$ and $R = 1\ M\Omega$,

$$E_o = -\int_0^t E_i\, dt$$

So far only one input voltage has been considered. The operational amplifier may, in fact, be used with several input voltages, each voltage being connected to its own separate input impedance. Consider the amplifier of Fig. 1 connected to n

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inputs as shown in Fig. 2. For large amplifier gain the approximation $E_g = -\frac{E_o}{A} \simeq 0$ is again used, giving:

$$I_1 = \frac{E_1}{Z_1}, I_2 = \frac{E_2}{Z_2}, \ldots I_n = \frac{E_n}{Z_n}, \text{and } I_f = -\frac{E_o}{Z_f}$$

The amplifier draws no current at its input grid, and therefore:

$$I_f = I_1 + I_2 + \ldots + I_n$$

This gives:

$$E_o = -\left[\frac{Z_f}{Z_1}.E_1 + \frac{Z}{Z_2}.E_2 + \ldots + \frac{Z_f}{Z_n}.E_n\right]$$

If the feedback and input impedances are all resistances then:

$$E_o = -\left[\frac{R_f}{R_1}.E_1 + \frac{R_f}{R_2}.E_2 + \ldots + \frac{R_f}{R_n}.E_n\right]$$

The input voltages are multiplied by constant coefficients and then added together. The amplifier output gives the value of this sum with its sign changed. Normally R_f is made equal to 1MΩ and the input resistances are chosen to give the desired coefficients.

If the feedback impedance is made a capacitor and the input impedances are all resistances:

$$Z_f = \frac{1}{P.C}, Z_1 = R_1, Z_2 = R_2, \ldots Z_n = R_n$$

Then

$$E_o = -\left[\frac{1}{CR_1}.\frac{1}{P}.E_1 + \frac{1}{CR_2}.\frac{1}{P}.E_2 + \ldots + \frac{1}{CR_r}.\frac{1}{P}.E_n\right]$$

or

$$E_o = -\left[\frac{1}{CR_1}\int_o^t E_1 dt + \frac{1}{CR_2}\int_o^t E_2 dt . + \ldots + \frac{1}{CR_n}\int_o^t E_n dt\right]$$

and the operational amplifier acts as a summing integrator.

The need often arises for multiplication by some

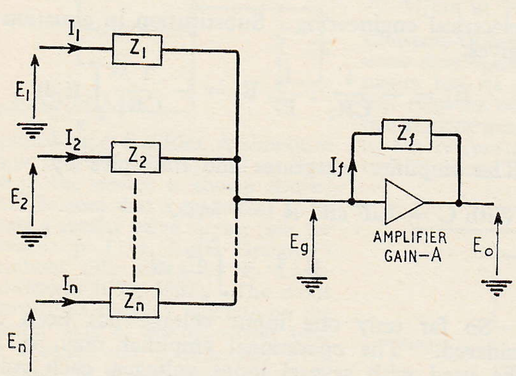


Fig. 2. The operational amplifier of Fig. 1 connected to a number of input voltages.

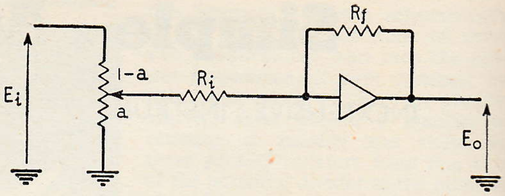


Fig. 3. Potentiometer used for multiplication by a constant.

easily changed constant. This is most conveniently accomplished by the use of a simple potentiometer (Fig. 3). In this circuit $E_o = -a\frac{R_f}{R_i}E_i$

This equation neglects the error introduced by the loading of the potentiometer. The error may be calculated or alternatively "*a*" may be set with the potentiometer on load. A further requirement is provision for setting initial values of the variable voltages. These "initial conditions," as they are called, are usually set before the start of a computer "run" as voltages across the feedback capacitors of the integrating amplifiers.

Provision for carrying out all the above operations has been included in the apparatus to be described. A more elaborate arrangement would probably include function generators and provision for multiplication by variables.[1]

Construction of Apparatus.—The apparatus consists essentially of five amplifiers, two of these being used as integrators or summing integrators, the other three as summers or sign changers. Amplifier input and output sockets are mounted on a panel. Short lengths of wire plugged into these sockets enable the connections between amplifiers necessary for the solution of a particular problem to be easily made. The fixed input and feedback impedances are mounted behind this panel, together with coefficient and initial-condition setting potentiometers. The amplifiers and front panel are mounted on top of the power supplies; these are commercially built stabilized supplies. The general layout of the apparatus should be clear from the photographs Figs. 4 and 5.

The gain of an amplifier used in an analogue computer must extend down to zero frequency, and this means that direct coupling must be used between the individual stages of the amplifier. This direct coupling introduces problems in the design procedure that are peculiar to this type of amplifier. The basic design considerations are:

(a) Interstage coupling techniques. Correct quiescent bias voltages must be placed on all grids, and this usually involves the use of resistive coupling dividers and extra negative power supplies.

(b) Balancing adjustment. It is necessary to provide a means of adjusting the output voltage to its desired quiescent level (usually earth potential) when the input is at zero signal level.

(c) Stability. Any small drift in the quiescent voltage levels in the first stage of a high-gain d.c. amplifier can result in a considerable change in the output level of the amplifier. Drift in the quiescent voltage levels may usually be attributed to one or more of the following causes: (1) small changes in the grid current flowing through the grid circuit

(*Continued on page 231*)

impedance; (2) variations in heater voltage which cause changes in the initial emission velocities of the electrons and so produce a change in the steady current through the valve; (3) variations in supply voltages; (4) changes in the value of circuit components and ageing of valves.

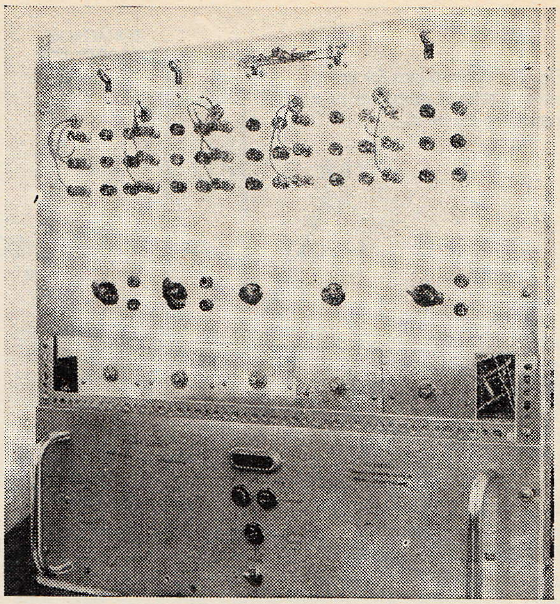
The above difficulties may be largely overcome by the use of a suitable circuit arrangement. All power supplies for use with d.c. amplifiers should, of course, be well stabilised. The reader is referred to the literature for a full treatment of the problems involved in the design of d.c. amplifiers.[2]

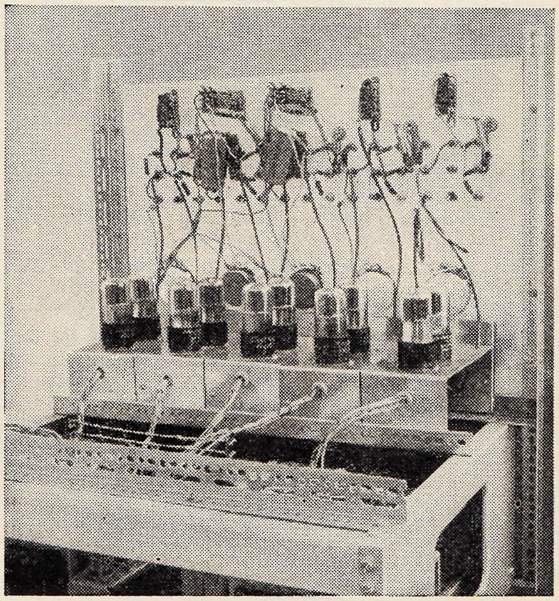
The d.c. amplifiers used by the author were chosen primarily for their simplicity. They use only one valve type and two power supplies. The circuit is illustrated in Fig. 6. This circuit was originally developed for computer use at the University of Michigan[3]. The first stage uses a double triode connected as a cathode-coupled amplifier, this method of connection giving some compensation for variations in heater and supply voltages.

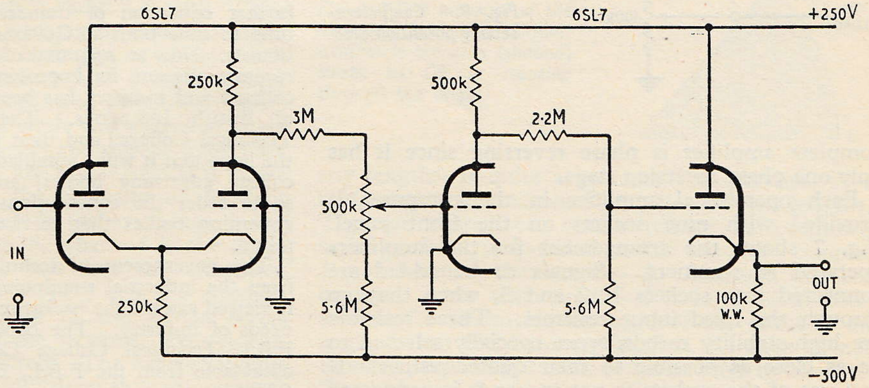
A cathode-coupled amplifier may be thought of as a cathode follower driving an earthed-grid amplifier. Cathode followers and earthed-grid amplifiers are both non phase-inverting stages, so the output from this first valve will be in phase with the input voltage. This output is directly coupled to the next valve by a resistive coupling divider. The resistances in this divider are chosen so as to put the correct quiescent bias on the grid of the next stage.

Adjustment of this bias is provided by the 500kΩ potentiometer, which serves as a balance control. Balancing the amplifier consists of connecting its input terminal to earth and adjusting this potentiometer to bring the output terminal of the amplifier to earth potential. This balancing operation has to be performed periodically to cancel out the effect of any small drift in the output level of the first stage. Drift would otherwise cause the amplifier to show an output even though its input were zero. Only a very small adjustment of the potentiometer is required and a value of 500kΩ is, in fact, rather large for the purpose. This value was used to give a greater tolerance for the values of the two resistances used in the coupling divider. The original circuit used a 50-kΩ potentiometer for the purpose. It was found to give a finer control but made the selection of the coupling resistance values rather critical.

The second valve of the amplifier is also a double triode. The first half of it is used as a normal voltage amplifier and the second half as a cathode follower to give the amplifier a low output impedance. The





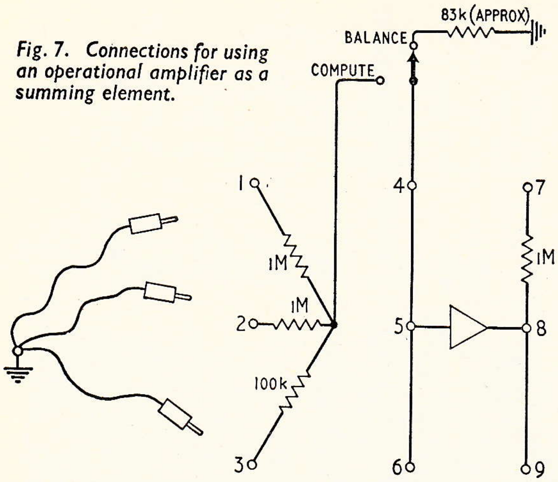


Top Right: Fig. 4. Front panel of the analogue computer, showing the connection sockets at the top and the five smaller panels of the d.c. amplifiers in the centre.

Centre Right: Fig. 5. Rear of the analogue computer, again showing the group of d.c. amplifiers, each on a small individual chassis.

Right: Fig. 6. Circuit of the d.c. amplifier used in the computer.

Fig. 7. *Connections for using an operational amplifier as a summing element.*



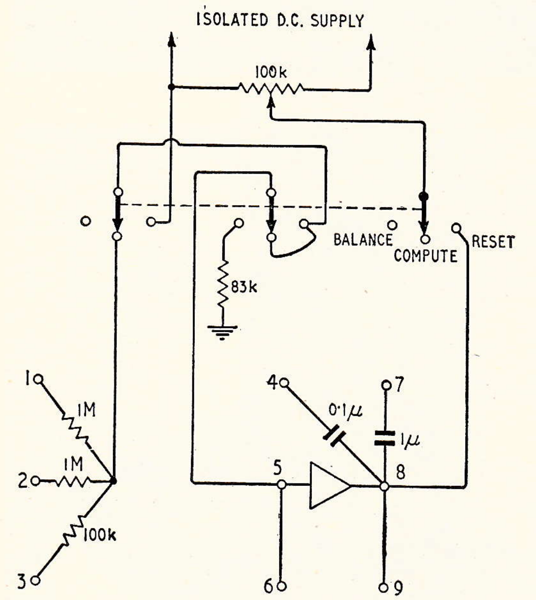


Fig. 8. *Connections for using an operational amplifier as a summing integrator.*

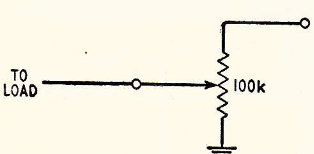


Fig. 9. *Coefficient-setting potentiometer*

complete amplifier is phase reversing since it has only one phase reversing stage.

Each operational amplifier in the computer is provided with nine sockets on the front panel. Fig. 7 shows the arrangement for the amplifiers operated as summers. Signals to be added are connected into sockets 1, 2 and 3, when they go through the fixed input resistors. These resistors are high-stability carbon types specially selected to be as close as possible to their quoted values. If any one of the sockets is not in use it is connected to earth. Sockets 4, 5 and 6 connect directly to the amplifier input. A 1-MΩ feedback resistor is connected between sockets 7 and 8 and is joined to the amplifier input by an external loop. The switch allows the amplifier input to be disconnected from any incoming signals and earthed through a resistor equivalent to the parallel combination of the three input resistors. In this position of the switch the amplifier balance control is adjusted to bring the amplifier output to earth potential. An external meter is needed for this balancing operation.

Fig. 8 shows the arrangement for the amplifiers operated as summing integrators. It differs from Fig. 7 in that feedback is through a capacitor. A 0.1μF and a 1μF capacitor are provided, the particular value required being selected by an external loop. A three-position ganged switch enables selection of "compute," "balance," and "reset" conditions. In the "compute" position, sockets 1, 2 and 3 connect to the amplifier input through the fixed input resistors, and again if a particular input is not in use it is earthed. In the "balance" position the amplifier input is connected to earth through a resistor equal to the parallel combination of the three input resistors. In the "reset" position the amplifier is lifted out of circuit and the desired initial voltage is set across the feedback capacitors. This voltage is controlled by means of the initial-condition setting potentiometer and is derived from an isolated battery supply (a grid bias battery has been used). The control switches for the two integrators are ganged together.

Coefficient-setting potentiometers are mounted on the front panel. Each is provided with two sockets (Fig. 9). The coefficients are set with the potentiometer on load by the use of a dry battery and valve voltmeter.

Next month the use of the computer to represent a simple mechanical system will be described.

REFERENCES

[1] "Electronic Analog Computers," by G. A. Korn and T. M. Korn, 2nd Edition, McGraw-Hill, New York, 1956.

[2] "Vacuum Tube Amplifiers," by G. E. Valley and H. Wallman, M.I.T. Radiation Laboratory Series, McGraw-Hill, New York, 1948.

[3] *Rev. Sci. Instr.*, 21, 154, 1950.

Technical Colleges

THE need for closer co-operation between technical colleges and industry—to their mutual benefit—in the further education of trainees has been stressed from time to time both at Government level and by educationists. Now an appraisal of the present situation, with recommendations for improving the relationship between colleges and industry has been made by the Federation of British Industries. The 44-page booklet "The Technical Colleges and their Government" is issued in the hope that it will "stimulate industrialists to serve [on college governing bodies] and lead Local Authorities so to order the constitutions and procedures of their governing bodies that service is a really worth while task".

The government of technical colleges is considered from the industrial standpoint and the present position is viewed against the background of the rapidly changing needs of industry. The booklet is issued by the joint F.B.I. Technical College Committee and copies are obtainable from the F.B.I., 21 Tothill Street, London, S.W.1.