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An Electronic Analog Computer for the General Physics Laboratory

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INTRODUCTION

Electronic analog computers are being increasingly used today in physics (1, 2), mathematics (3), and engineering (4), and we believe they are valuable as an instructional aid in a college physics department. We have found that the construction of this computer illustrated important electronic principles to our students, motivated them in their study of differential equations, gave them techniques that can be applied to problem-solving on any analog computer, and provided them solutions of some of the important equations of physics.

THEORY OF THE OPERATIONAL AMPLIFIER

The essential part of our computer consists of 12 dc operational amplifiers. Figure 1 shows the circuit of one of these amplifiers (5). Figure 2 gives the fundamental equation for the amplifier used as an adder. E is the output voltage with respect to ground, when E_1, E_2, and E_3 are the input voltages with respect to ground. If the feedback resistance $R = 1$ megohm, and if the input resistances R_1, R_2 and R_3 are respectively 1, ½, and ⅕ megohms: $E = -(E_1 + 2E_2 + 5E_3)$. Such a (negative) adding circuit is conveniently represented schematically as in Figure 2.

When a feedback capacitance C mfd is substituted for R, the amplifier functions as an integrator, with the equation shown. If $C = 1$ mfd, and if R_1, R_2, and R_3 are respectively 1, ½, and ⅕ megohms; the output voltage $E = -\int(E_1 + 2E_2 + 5E_3)\,dt$, and this (negative) integrating circuit is represented schematically as indicated.

CONSTRUCTION OF THE COMPUTER

The components of the computer are mounted on 19 inch aluminum rack panels. The DC voltage supply consists of two conventional radio power supplies of +250 and –300 volts. The AC input voltage is maintained approximately constant by adjusting a Variac. The accuracy of the computer is dependent on the voltage regulation.

The computer provides six operational amplifier units, one of which is shown in Figure 3. The physical appearance of the panel of one of these units is shown in Figure 4. Each unit comprises an

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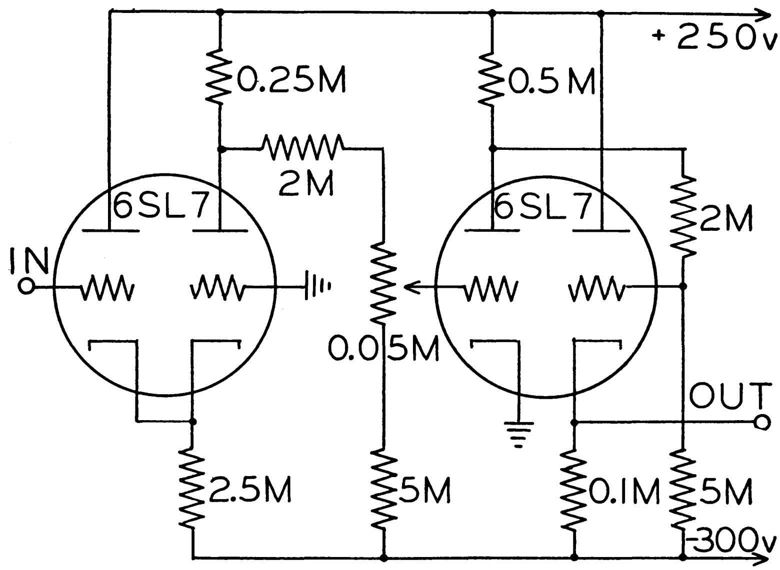

Fig. 1. Operational Amplifier.

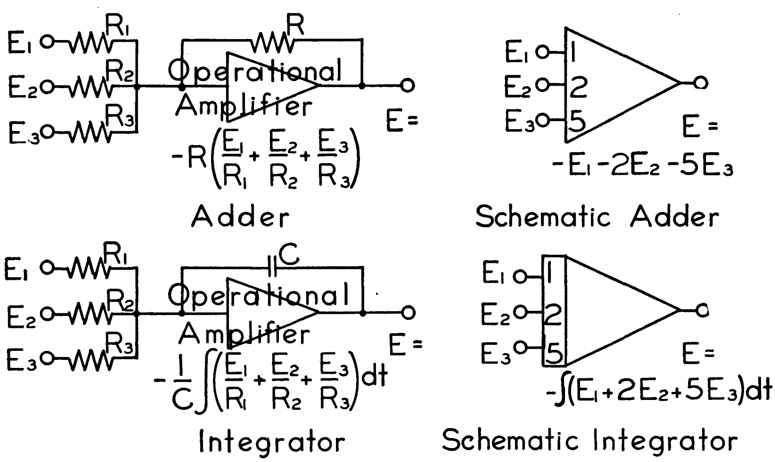

Fig. 2. The Operation Amplifier as an Adder and as an Integrator.

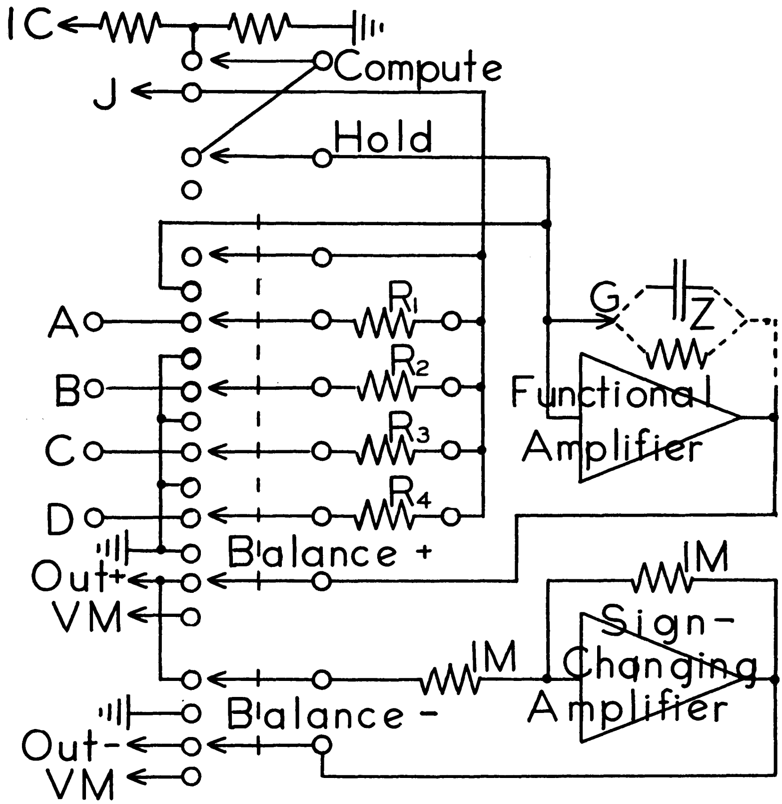

Fig. 3. Operational Amplifier Unit.

amplifier which will function either as an adder or an integrator by plugging a resistance or a capacitance into the "Z" jacks. Input voltages are applied at the input jacks A, B, C, and D, through the input resistances R_1, R_2, R_3, and R_4. These resistances are conveniently mounted in G-R double plugs. The amplifier output appears at the four jacks marked "Out +", and is fed into the sign-changing amplifier whose output appears at the four jacks marked "Out –". A neon lamp "OL" is connected across these two outputs as a warning to prevent overloading the amplifiers.

Operation

Before starting a computation, each individual amplifier must be balanced to zero output, when the input is grounded through a resistance equal to the parallel combination of the input resistances. This is accomplished by depressing the "normally up" "Balance" switch, and adjusting the 0.05 M potentiometer of Figure 1 until the voltmeter indicates no deflection.

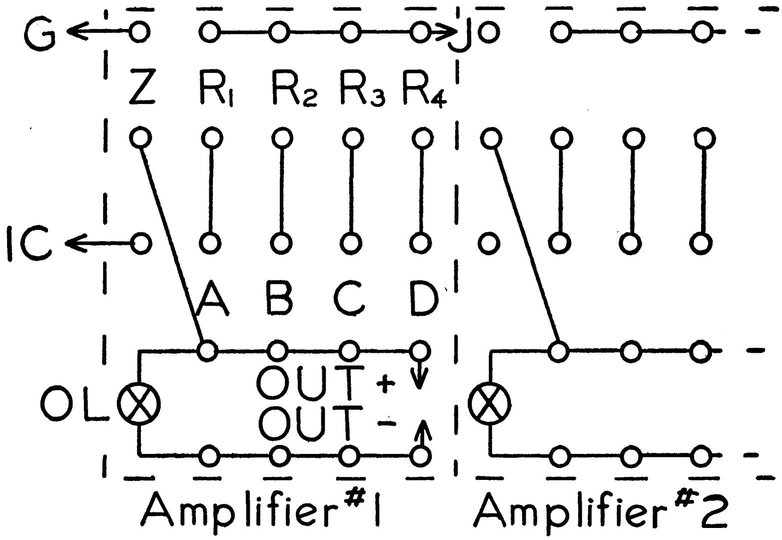

Fig. 4. Operational Amplifier Panel.

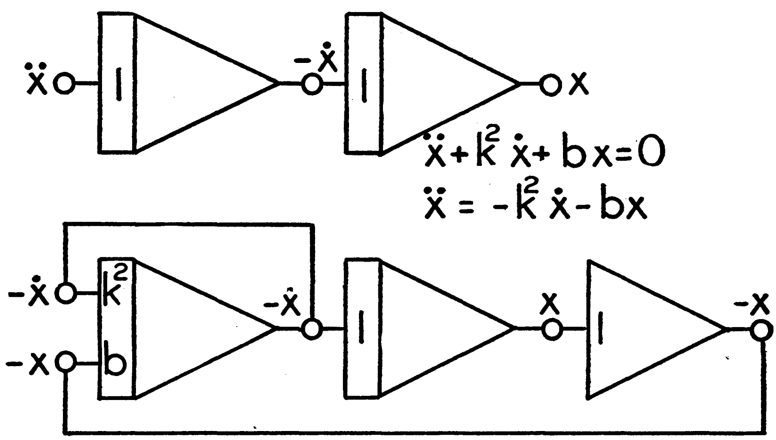

Fig. 5. Solution of Damped Harmonic Motion Equation.

Mounted on the panel are a "Compute" and a "Hold" switch, along with a voltmeter on which the solutions are shown. When the "Compute" switch is depressed, the input resistors are connected to the amplifiers and computation begins. The computation can be stopped at any time by depressing the "Hold" switch; and the output voltmeter continues to indicate its last reading.

Solution of Differential and Simultaneous Equations

The general principles of solving differential equations are illustrated in the top part of Figure 5, where they are applied to the equation of damped harmonic motion. The practical computer circuitry is shown in the bottom part of the figure. In order that the values of the constant coefficients of the equation be not limited to the discrete values imposed by the input resistors, a potentiometer panel is provided, whose operation is shown in Figure 6. A Heli-pot potentiometer permits closer adjustment than the conventional potentiometer.

Methods of solving linear simultaneous equations by integrators or by adders are indicated in Figure 7. For equations in 3 unknowns, either 3 integrating units or 3 adding units are required.

Summary

During the first few months the computer has been in operation, we have used it to illustrate many physical laws such as: distance and velocity relations in uniform acceleration, motion with resistance proportional to velocity, thermometric lag, motion of ballistic galvanometer, and radioactive decay. It is our belief that the computer serves as a useful motivating device and instructional tool in the general physic laboratory.

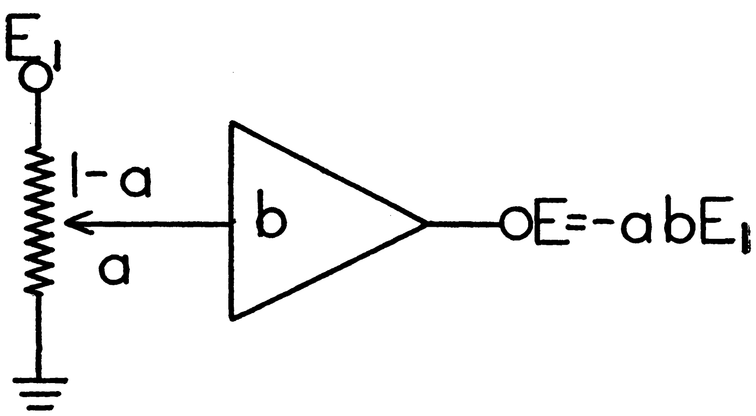

Fig. 6. Use of Coefficient Potentiometer.

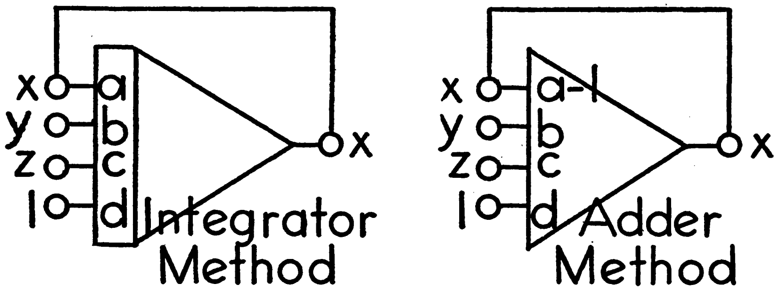

Fig. 7. Use of Integrators and Adders to Solve Linear Simultaneous Equations: $ax + by + cz + d = O = -dx/dt$; $kx + ly + mz + n = O = -dy/dt$; $px + qy + rz + s = O = -dz/dt$. Two additional amplifiers are required to give the outputs y and z.

ACKNOWLEDGMENT

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