CHAPTER 17

REPETITIVE, A.C., MAGNETIC, TRANSISTOR, AND THERMAL COMPUTERS

17.1 INTRODUCTION

The major emphasis in Vols. 1 and 2 has been on functional general-purpose real-time d.c. computer, although components of other computers have been discussed. In particular, the last few chapters of Volume 2 contain rather detailed descriptions of the circuitry and design features of the d.c. computer. This appears to be a felicitous point to introduce, in a general manner, several computers closely related to the d.c. computer, namely, the high-speed repetitive computer, customarily a d.c. computer, which is discussed in Sec. 17.2, and the general-purpose a.c. computer, discussed in Sec. 17.3. The latter is distinguished from the a.c. network analyzer (Chap. 19), which is usually employed as a direct, rather than a functional, analogue. Most of the computing techniques which have been introduced with respect to the d.c. computer are equally applicable to the repetitive and a.c. computers and do not warrant repetition. Therefore, the following sections are devoted primarily to a description of the types of components in these machines and to a comparison of their characteristics with those of the previously discussed d.c. computer.

Inasmuch as the a.c. computer is historically the forerunner of both the real-time and the repetitive d.c. machines, it has received more extensive treatment in the engineering literature to date. We shall find particular reference to it in the following chapters which deal with special-purpose computers, such as simultaneous and secular equation solvers, many of which were designed prior to World War II. The d.c. computer first came into its own during the war. The a.c. computer is still used almost exclusively in certain areas of computation, where the d.c. computer might be equally applicable, but where it is deemed an unproven tool. This resistance to experimentation or change is most in evidence in the field of flight simulators and trainers (Chap. 28), which are fundamentally a.c. computers at this time. What is perhaps the first large-scale d.c. trainer (for submarines) was designed and constructed in 1955–1956.* Among the chief advantages of the a.c. trainer, according to its

* The noteworthy success of this computer has led to the increased acceptance of d.c. computers as trainers.

proponents, are (1) the fact that most instruments to which the computer inputs and outputs are connected are also a.c., (2) the relative simplicity of the power supply system which is required, and (3) the freedom from drift in a.c. computation. (Prior to the advent of the chopper-stabilized d-c amplifier, drift was a serious problem in d.c. computers; see Chap. 2.) We shall have occasion to discuss the relative merits of d.c. and a.c. computation later.

Two more recent developments in analogue computers are described in Secs. 17.4 and 17.5. One makes use of magnetic amplifiers and the transistor type of semiconductor. Magnetic amplifiers have been employed for some fifty years; transistors were first reported upon in 1948–1949.[1,2,*] The two examples of computers comprised of magnetic and transistor units described are (1) an electronic multiplier of the time-division type, and (2) an a.c. computer whose principle of operation is based on the use of two carriers rather than the conventional single carrier.

The second development is a thermal analyzer which functions with either direct or alternating current. Its theory of operation is relatively simple, being based on the relation between current and temperature changes in a resistive element.

17.2 THE REPETITIVE COMPUTER

Considerable popularity is enjoyed by a class of high-speed repetitive machines which, as the name denotes, generally operate at time scales faster than real time.[3–16] The design of these computers is such that the solution is repeated at short periodic intervals. The ratio of high-speed computer time to real time may be in the order of several thousand to one, and generally ten or more solutions are produced per second. Computer circuits are required which periodically introduce forcing functions for the generation of the solution. At the completion of each solution, the system is returned to the zero equilibrium state and the entire process is automatically repeated. A cathode-ray tube (see Chap. 10) with a sweep synchronized with the computer is used to display the solution. This gives a repetitive representation which appears stationary, and makes it possible to vary the parameters of the physical system and to observe the effect of these changes on the oscilloscope. The components of the repetitive computer, linear as well as nonlinear, are electronic and must be capable of high-speed operation, in the kilocycle range.

Repetitive computers employing both capacitance-coupled and direct-coupled amplifiers have been designed. The MacNee computer devel-

* Superscript numbers indicate references, which, throughout the book, will be found at the ends of chapters.

oped at MIT falls in the first category.[17] While there appear to be certain advantages to this form of computing, e.g., simplicity in amplifier and power supply design, this computer has not been exploited commercially. The most notable exponents of the second group are the computers manufactured by George A. Philbrick Researches, Inc., and by GPS Instrument Co., Inc., and which are available commercially. The accuracy and precision of the repetitive computer are somewhat poorer than that of the real-time functional computer described in the previous chapters. Some real-time functional computers have added a repetitive mode

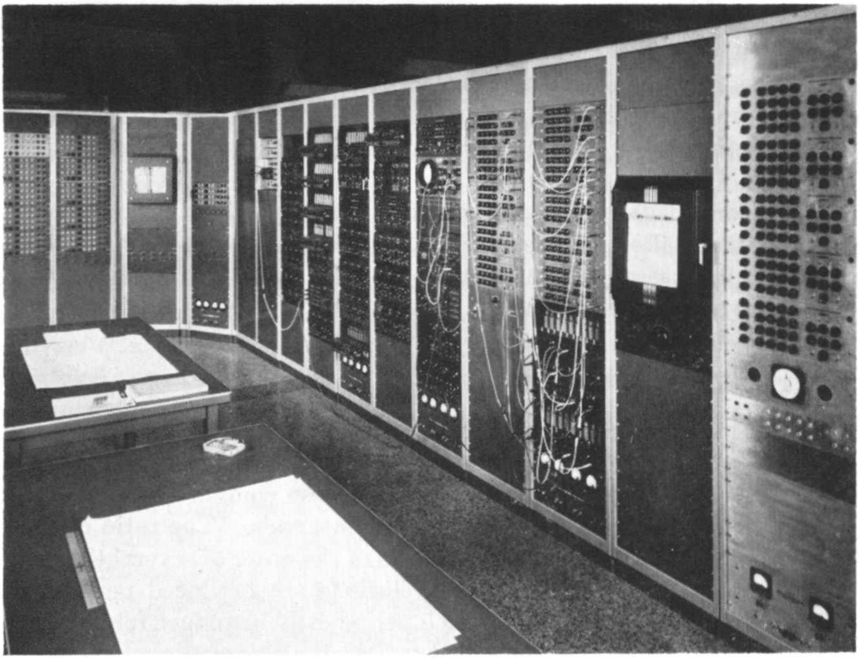
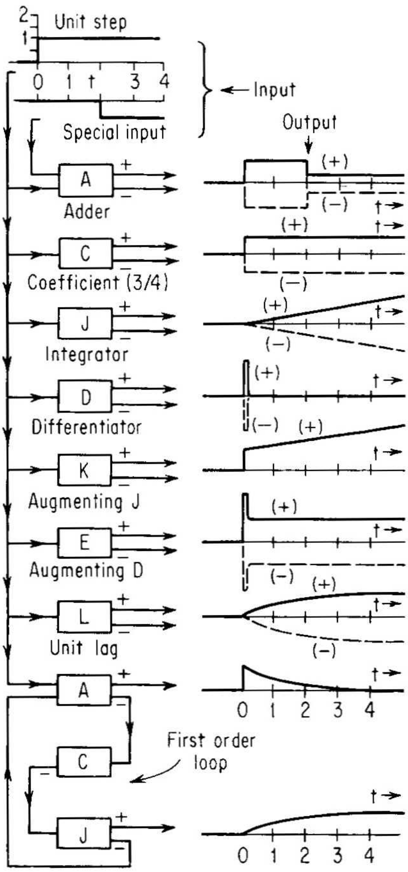


FIG. 17.1. Photograph of Philbrick computer.

of operation. The Electronic Associates computer, for example, allows for a maximum repetition rate of 6 cps to effect a compromise between speed and accuracy.[18] It is also more difficult to solve linear time-varying or nonlinear problems on the repetitive computer. This arises from the difficulty in designing multipliers and function generators which are capable of both high accuracy and high frequency response (see Chaps. 5 and 9). Component accuracy ranges from 1 to 2 per cent; the over-all accuracy ranges from 5 to 10 per cent.[4] A higher order of accuracy is sometimes obtainable. This, of course, depends on the complexity and nonlinearity of the problem which is being solved. The repetitive computer, by virtue of its speed and oscillographic recording, has proved to be an excellent tool for preliminary design studies, as shown, for example, by Concordia and Kirchmayer.[19] It has also served as a teaching aid by the inclusion of a projection type of oscillograph for producing a large picture on a screen.[20]

TABLE 17.1



The philosophy of the Philbrick computer is based on constructing the analogue of a physical system by means of "building blocks." Each one of the basic linear and nonlinear operations is performed by an individual computer unit which is housed as an individual assembly and which contains input and output jacks for connection to other units. Thus, in contrast to the general-purpose functional d.c. computer which consists of complete cabinets and consoles, the individual components here are generally assembled in racks in the types and numbers as required (Fig. 17.1).

The linear units include the following components designated as noted:

Integrator	J	Augmenting J	K
Differentiator	D	Augmenting D	E
Adder	A	Unit lag	L
Coefficient	C	Dynamic	Dy

These units are represented functionally in Table 17.1, where the response of each component to a unit step is shown.* Each of the last four linear units carries out the combination of several linear operations, representing the solution of a first- or a second-order linear differential equation with constant coefficients.

The nonlinear units include the following components designated as noted:

Bounder (or limiter)	B	Absolute value	V
Backlash (or hysteresis)	H	Multiplier	Mu
Inert-zone (or dead-zone)	Z	Function fitter	FF
Squarer	S	Modified square	σ
Square root	T	Modified square root	τ

The units are represented functionally in Table 17.2, where the responses to sinusoidal inputs are shown.† The last column in this table is a plot of output versus input.

Each computing unit is comprised of two feedback amplifiers, so that both positive and negative outputs are available, the second amplifier being used for sign inversion. To simplify the following discussion, only one of the outputs will generally be denoted. The maximum voltage range is $+50$ volts. The open-loop gain of the operational amplifier is approximately 15,000 to 30,000. (Chopper-stabilized amplifiers are also available with gains of approximately 10^8.)

Time Scale. A representative computing cycle of the computer is 0.08 sec; one half (0.04 sec) is devoted to the actual solution; the other half is devoted to returning the outputs of all integrators to zero. Thus, the time scale of the problem is compressed, in general, to accommodate the period of 0.04 sec. (Faster or slower computation is also possible.) Now let us assume that the actual physical problem under study has a duration of 120 sec. If t denotes real time and τ computer time, then the substitution (see Chap. 4)

$$t = k\tau \tag{17.1}$$

* The representation of the dynamic unit is not included in Table 17.1.

† The representations of the multiplier and the function fitter units are not included in Table 17.2.

is made, where $k = 120/0.04 = 3{,}000$. Each integral

$$y = \int x\, dt \tag{17.2}$$

is transformed into

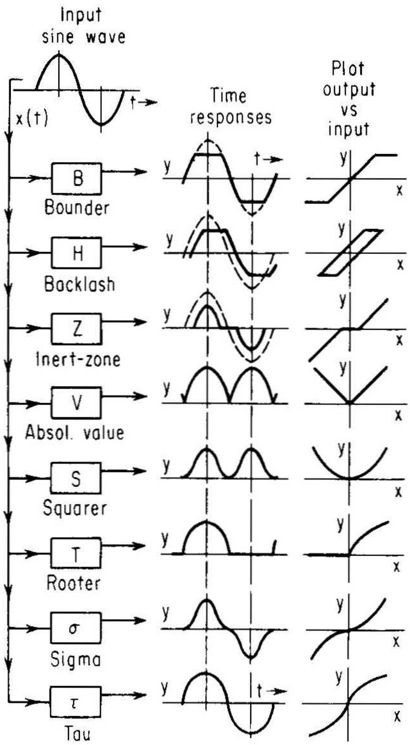
$$y = 3{,}000 \int x\, d\tau. \tag{17.3}$$

The integrators are designed to satisfy one of the relations

$$\begin{aligned} y &= \int x\, d\tau, \\ y &= 250 \int x\, d\tau, \\ y &= 2{,}500 \int x\, d\tau. \end{aligned} \tag{17.4}$$

Referring to the last relation given in Eq. (17.4), it is evident that the additional gain of $3{,}000/2{,}500 = 1.2$ is necessary at the output of each

TABLE 17.2



integrator. To compensate for this factor, the designation of each integrator output is, therefore, 1/1.2 of its nominal value, i.e., the output is given by $3{,}000 \int x\, d\tau / 1.2$. A coefficient unit, to be described later, introduces any necessary scale factors.

Repetitive Solutions and Clamping. A double-step wave made up of four sections consisting of a positive step, zero, a negative step, and zero, each of 40 msec duration, is used as a forcing function for the given system, as shown in Fig. 17.2, with a solution being generated whenever there is a positive or negative step. The double-step wave is modified to form a square wave which is positive whenever the value of the double-step wave is zero and which is negative whenever the value of the double-step wave is either positive or negative. The positive portions of the square wave are employed to clamp the integrator outputs at zero (corresponding to the reset position on the functional computer, Chap. 2). Clamping of the integrators may not be necessary in stability problems in which the solutions may normally decay to zero. A nonzero initial condition for the output of an integrator is treated as a step added to the output. (The steps are obtained from the square wave.) For example, if x is the desired output of an integrator and $x(0) = X$, then the omission of the necessary initial condition on the integrator is equivalent to converting the output to the quantity $x - X$. The constant term X is added as a step function to the output of the integrator to give x.

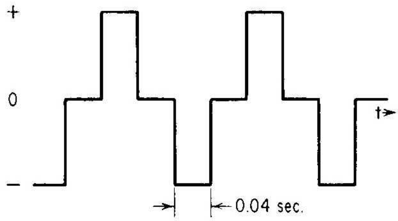


FIG. 17.2. Double-step wave.

Linear Components

Integrator (J). The J component, or integrator, yields the relation

$$y = \frac{1}{T_0} \int x \, dt \tag{17.5}$$

where T_0 may have the values 0.0004, 0.004, or 1 sec. The integrator (Fig. 17.3) is similar to the conventional d-c electronic integrator

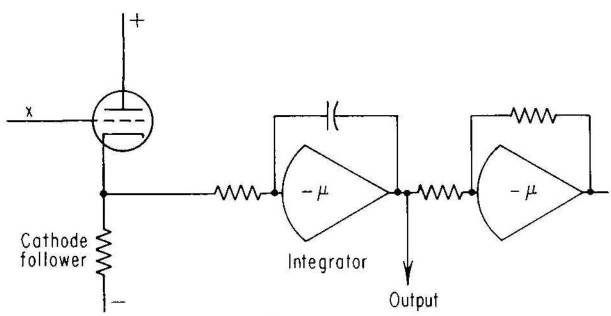


FIG. 17.3. Integrator circuit.

described in Chap. 2, with an input resistor and a feedback capacitor. As stated before, it must be capable of operation at frequencies in the