An Improved Multichannel Drift-Stabilization System

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AT PRESENT, all but the smallest d-c analogue computers employ some method of drift stabilization to reduce drift at the output of the computing amplifiers. The method most often used is called chopper stabilization.[1] With this method, some drift-free gain is added to the forward loop of a d-c feedback amplifier. If the added drift-free gain is placed in the loop ahead of the primary sources of drift, the steady-state drift with stabilization is equal to the drift without stabilization divided by the amount of drift-free gain added. The required drift-free gain can be achieved with a chopper and an associated stabilization amplifier.

By the technique of single-channel chopper stabilization, excellent drift stability can be obtained, particularly with well-built and well-shielded choppers such as the Leeds and Northrup unit. Unfortunately, during a 5-year period, experience with a large number of choppers at the Dynamic Analysis and Control Laboratory (DACL) at the Massachusetts Institute of Technology has shown that maintenance of these choppers is necessary after their first year of operation, and, as the choppers become even older, they must be maintained more and more frequently. Also, the amplifiers associated with each chopper must be checked periodically. In a large installation with more than 200 computing amplifiers, such maintenance presents a problem. Another difficulty is that these choppers are bulky, and they, together with the added amplifiers, prevent the construction of smaller computing amplifiers. These disadvantages of single-channel chopper stabilization are avoided by using multichannel drift stabilization.

Multichannel drift stabilization[2] is an extension of the chopper-stabilization technique. In the multichannel system as shown in Fig. 1, one stabilization system is time-shared by a group of d-c amplifiers, thus effecting a reduction in equipment size, cost, and maintenance. Unfortunately, the multichannel systems in use at the time that work began on the DACL system were inferior in some respects when compared with single-channel systems. For example, sufficient gain could not be achieved in the common stabilization amplifier to eliminate the need for a balancing adjustment in the computing amplifiers and in the stabilization amplifier. Crosstalk existed between channels, particularly if one channel was badly overloaded. Also, none of the systems at that time incorporated overload indicators that operated at the incidence of an overload and remained on after the overload until reset by the problem operator.

The design techniques described in this paper extend the usefulness of a multichannel system by eliminating some of these defects. The problem of eliminating crosstalk between computing positions without sacrifice of stabilization gain has been solved by the use of intermittent feedback and self-biased diodes, and the problem of providing a useful overload indicator has been solved by sampling the size of the signal in the stabilization system and by igniting gas tubes when an overload exists.

These techniques are now incorporated in a multichannel system in a small computer at the DACL. The computer has 30 d-c computing positions all of which are drift-stabilized with one commutator and one stabilization amplifier. The computing amplifiers require about 1/6 the volume of the older, single-channel chopper-stabilized amplifiers. The maintenance required is negligible when compared with the older units.

The response speed and the transient characteristics of this multichannel system as well as a statistical evaluation of the drift encountered in the DACL computing positions have been described elsewhere.[3]

Theory of Operation

In the multichannel system of Fig. 1, one stabilization amplifier is used to stabilize the 30 d-c amplifiers with the aid of a single commutator that samples the summing-point voltage of each amplifier in turn. Any direct voltage present at the summing point of an amplifier is applied to the stabilization amplifier as a pulse occurring at the repetition frequency of the commutator. These pulses, after being amplified, essentially without drift, and inverted in the stabilization amplifier, are channeled to the same d-c amplifier by the output section of the commutator and applied as a stabilization voltage through a smoothing filter. The computing amplifiers are conventional high-gain d-c amplifiers.

The stabilization circuit is used also for overload indication. When any d-c amplifier in the computer is overloaded, a large d-c error voltage appears at its summing point. This voltage is sampled by the input section of the stabilization switch, and the resulting pulses are amplified by the stabilization amplifier (see Fig. 1). Whenever the pulses in the stabilization amplifier exceed a predetermined level, they trigger a monostable multivibrator. The large, positive output pulses from the multivibrator override the normal output of the stabilization amplifier and are applied through the output section of the commutator to the overloaded d-c amplifier. In the d-c amplifier, where the large size of these pulses distinguishes them from a normal stabilization output, they are detected and used to trigger an overload indicator.

The Stabilization and Overload-Indication Unit

Fig. 2 is a schematic diagram of the stabilization and overload-indication unit circuitry. Tubes *V1*, *V2*, *V3*, and the first section of *V4* constitute the amplifier section. This is a conventional d-c amplifier. To eliminate drift in this amplifier, its gain is reduced between pulses to less than one by briefly closing a feedback path, as shown in Fig. 3. Each time the input grid of the stabilization amplifier is grounded, the charge on capacitor *C* in Fig. 3 is adjusted to the value required to keep the quiescent amplifier output very nearly at ground potential. No energy-storage elements appear in the stabilization-amplifier circuit during the time it receives signals from the computing-amplifier error points. The rotor of the input section of the commutator is wider than the rotor of the output section in order to ensure that the input be grounded whenever the stabilization-amplifier feedback loop is closed; therefore, crosstalk between adjacent

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ERRATA

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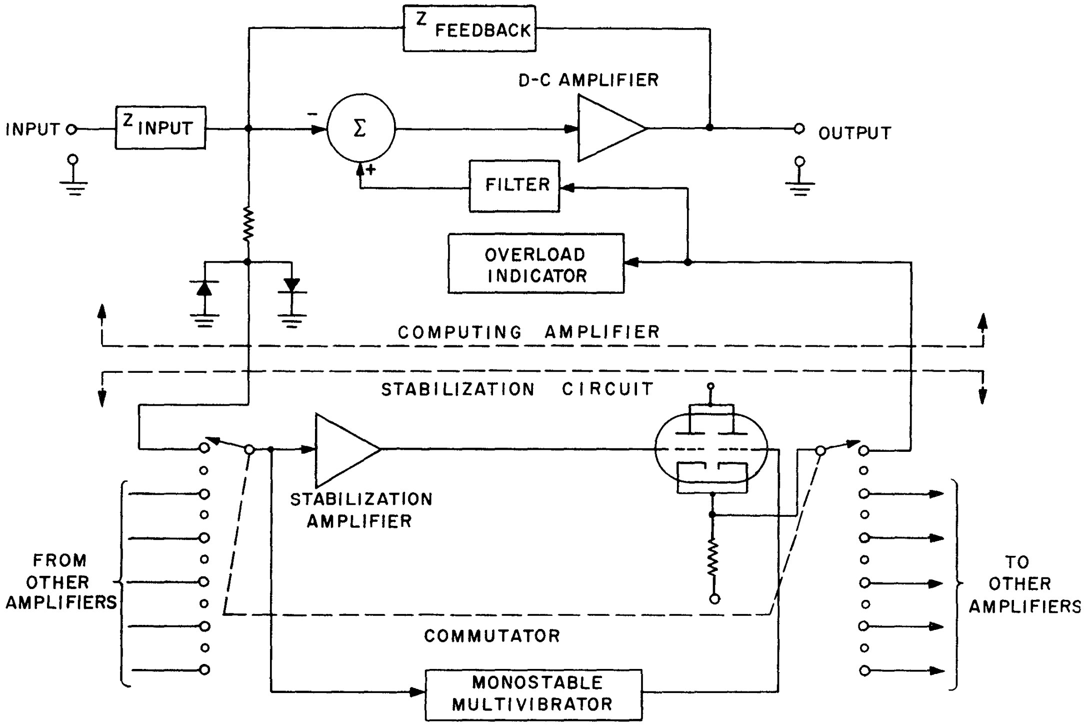

Fig. 1. Stabilization circuit with typical d-c amplifier

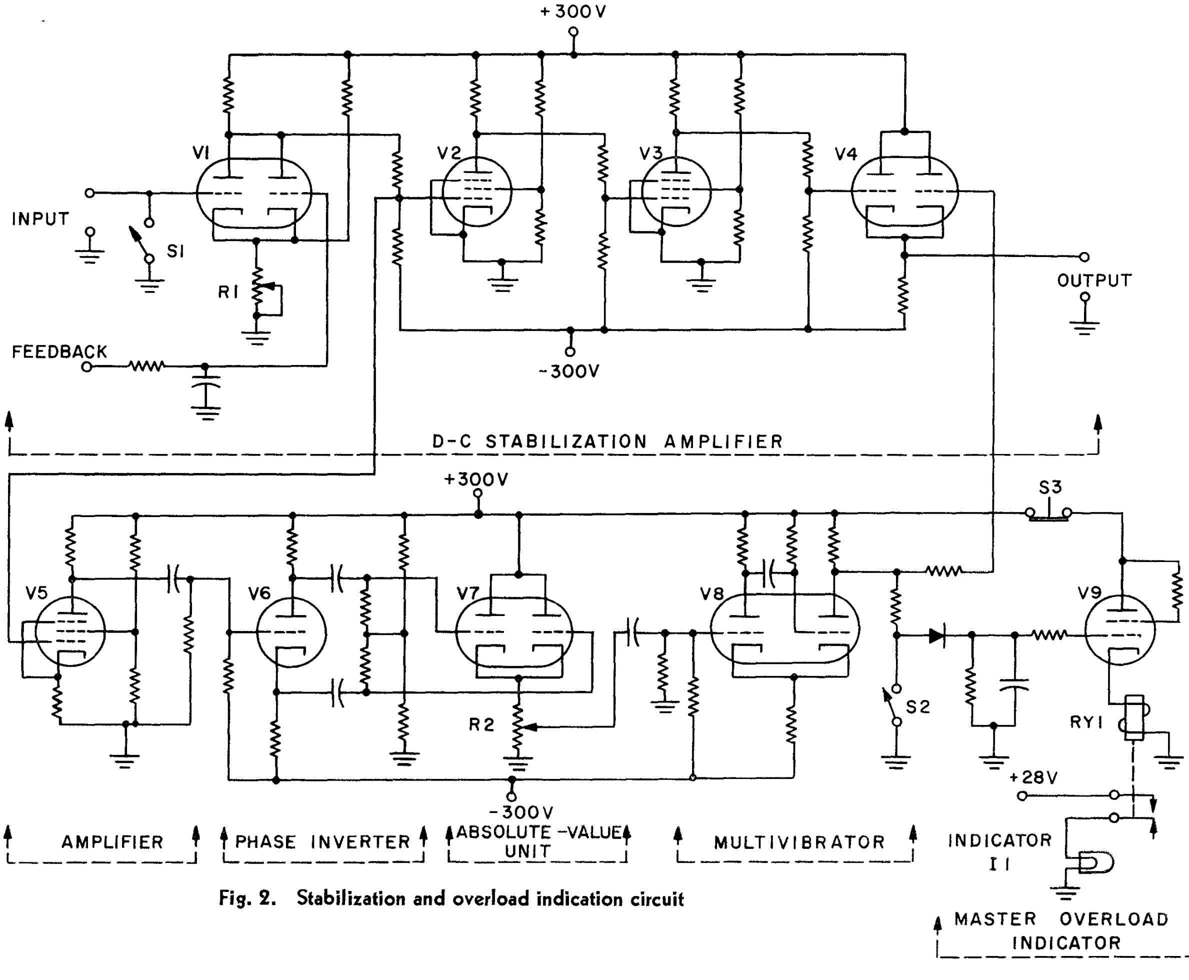

Fig. 2. Stabilization and overload indication circuit

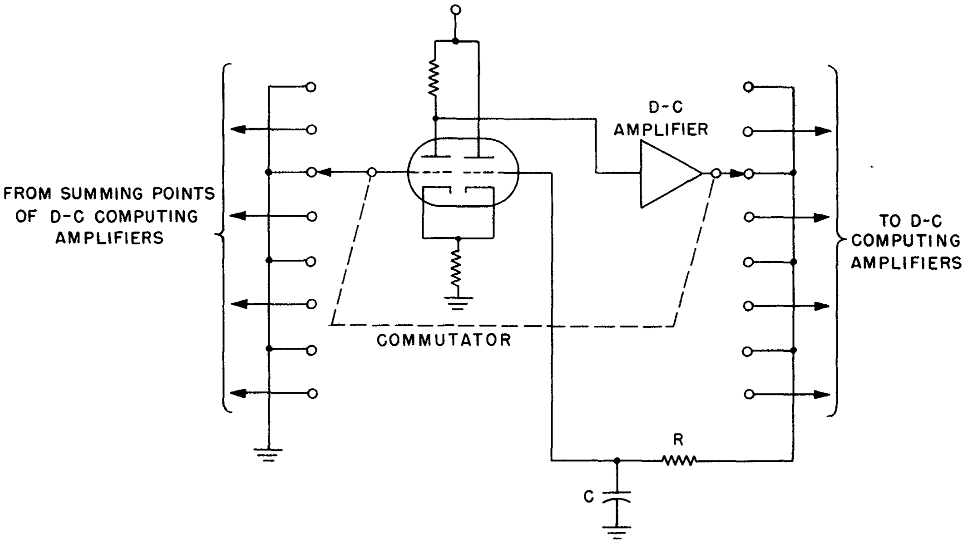

Fig. 3. Simplified stabilization on amplifier circuit

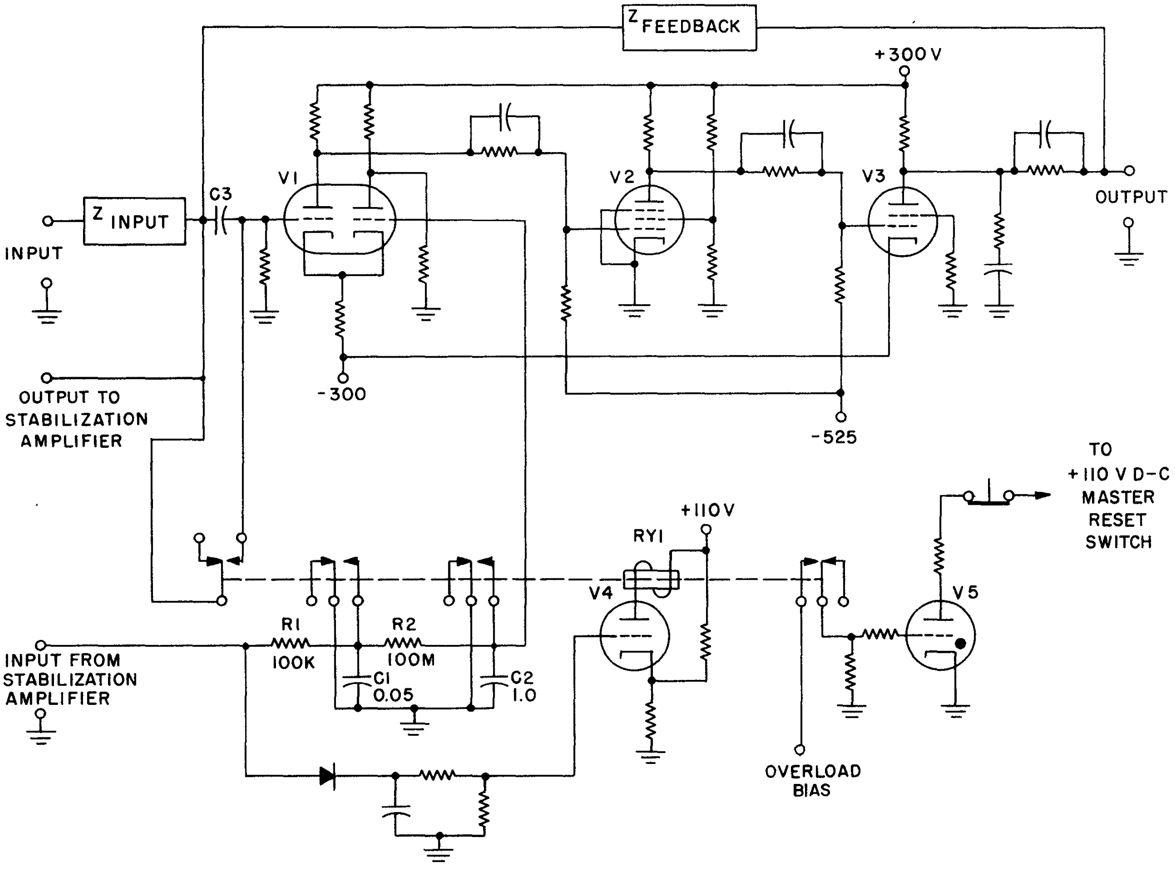

Fig. 4. Computing-amplifier unit

computing channels as the commutator rotates is not possible in the amplifier. The commutator used in this system is built by the Applied Science Corporation of Princeton, N. J., and is designed specifically for use in drift-stabilization circuits. It is a 60-position single-pole 2-deck switch that rotates approximately four times per second.

The centering control *R1* in Fig. 2 is provided to allow the output of the amplifier to be adjusted to ground potential when the input is grounded by switch *S1*. This adjustment, which allows the output to be set easily to within 100 millivolts of ground, is very stable and need be made only when a tube has been replaced in the stabilization amplifier or after a component failure has been repaired. The stabilization amplifier has a gain of approximately 2,000.

OVERLOAD-INDICATION CIRCUITRY

The remainder of the circuitry in Fig. 2 is used in the following way for overload indication:

1. Overload-signal amplifier *V5* amplifies the pulses at the grid of *V2*.
2. Phase-inverter *V6* makes a push-pull signal of the output of the amplifier *V5*.
3. Tube *V7* acts as an absolute-value device in that it inverts the sign of negative input pulses while not affecting positive input pulses.
4. Potentiometer *R2* sets the trigger level of the multivibrator *V8*. It does this by setting the magnitude of the pulses so that a predetermined overload voltage at the error point of any d-c amplifier produces a pulse just large enough to trigger the multivibrator.
5. The two sections of *V8* with their associated circuitry constitute a monostable multivibrator. This multivibrator is triggered by any large positive pulse applied at its input. When idle, the first section of the tube is cut off, and the second section is conducting with a plate voltage of −100 volts. When triggered, the first stage conducts, and the second stage is cut off. The second-stage plate voltage then is equal to the supply voltage of +300 volts.
6. The large pulses from the output of the multivibrator are applied to one grid of *V4* where their magnitude is sufficient to override any input to the other grid. Thus, the output of *V4* always is determined by the multivibrator output whenever the multivibrator is triggered. When the multivibrator is idle, the second section of *V4* is cut off and inoperative, and the first section operates as a cathode follower.
7. Tube *V9* is triggered by the multivibrator pulses, and it in turn energizes the relay *RY1*. The relay contacts are used to turn on a master overload indicator *I1*. Tube *V9* can be extinguished by removing its plate voltage with switch *S3*. The existing status of tube *V9* (on or off) can be retained independently of multivibrator pulses by grounding the overload-bias lead with *S2*. The master overload indicator is ignited by an overload in any of the 30 computing amplifiers.

VOLTAGE-LIMITING NETWORK

As shown in Fig. 1, back-to-back silicon diodes are used to limit the voltage swing at the input to the stabilization switch. Voltage limiting is necessary to prevent crosstalk between computing channels through the leakage in the insulation between contacts of the switch. Silicon diodes are used because their forward resistance is high until approximately 0.5 volt is applied in the forward direction. Thus, they have essentially a built-in bias of 0.5 volt, and no bias supply is needed. Conventional germanium diodes and a bias supply cannot be used because their back resistance is not high enough to prevent current flow from the bias supply when the diodes are not conducting. Any current flow at this point can reach the computing-amplifier summing point and can cause an offset at the output of the computing amplifier.

Stabilization and Overload Circuitry in the Computing Amplifier

Fig. 4 shows the circuit of a computing-amplifier unit. The unit contains a conventional high-gain d-c amplifier as well as some overload-indication and drift-stabilization circuitry. The circuitry used for overload indication and for filtering the stabilization-amplifier output is shown in detail.

STABILIZATION FILTER

As shown in Fig. 1, the stabilization commutator and amplifier sample the summing-point voltage of each amplifier, and deliver output pulses with peak values approximately 2,000 times the summing-point voltage. The pulses occur every 1/4 second and are 4 milliseconds long. Because the output stage of the stabilization system is a cathode follower and because a mechanical switch is used, the driving impedance is low when a pulse occurs and high between pulses. Consequently, *R1* and *C1* act as a holding circuit, and a steady voltage equal to approximately the pulse magnitude is developed across the capacitor *C1* in Fig. 4. (The time constant *R1* times *C1* is small.) The filter section *R2* and *C2* further smooths the voltage appearing across *C1*. The voltage applied to the second grid of the differential amplifier *V1* is at very low frequencies nearly an exact replica of the summing-point voltage multiplied by approximately 2,000. A large voltage applied across capacitors *C1* and *C2* in the stabilization filter causes dielectric absorption. The relay *RY1* is used to prevent this large voltage from occurring by short-circuiting the capacitors when an overload occurs. The d-c amplifier input coupling capacitor *C3* likewise must be short-circuited for the same reason. Short-circuiting these capacitors also reduces overload recovery time. Overload recovery time is 5 seconds or less, depending on the type of overload.

OVERLOAD-INDICATION CIRCUIT

As already described, when an overload occurs in a d-c amplifier, a large voltage appears at the d-c amplifier summing point. This voltage is sampled by the stabilization switch, and the resulting pulses are amplified in the stabilization-amplifier unit shown in Fig. 2. The presence of pulses larger than a predetermined value is sensed in the stabilization amplifier, and a triggered multivibrator produces very large positive output pulses. These large output pulses are directed by the output section of the stabilization switch to the overloaded d-c amplifier.

In the d-c amplifier, the large pulses trigger relay *RY1* which in turn short-circuits the proper capacitors to prevent dielectric absorption. Also, the relay ignites a *1C21* thyratron (*V5*) whose glow provides visual indication of the overload. When the overload indicator (*V5*) is triggered, it remains ignited until manually reset either by switch *S1* or by a master reset switch which simultaneously removes the plate voltage from tube *V10* in every amplifier.

To clamp the overload indicators so that their status (on or off) at any time can be retained independently of the occurrence of further overloads, the d-c overload bias voltage is removed. When the voltage is removed, the overload relay (*RY1*) is unable either to ignite or to extinguish the indicator tube (*V5*).

Conclusions

A multichannel drift-stabilization system with high gain and negligible crosstalk has been attained. With proper care taken to prevent pickup and to provide good signal grounds, the degree of drift stabilization obtained with a multichannel system is equivalent to that of a single-channel system. The following specifications are met by this system:

1. The stabilization channel gain is high enough (approximately 2,000) to reduce drift and offset referred to the summing point of the computing amplifiers to less than 1 millivolt. No balancing control is incorporated in the computing amplifiers.

2. Virtually no crosstalk occurs between computing positions even if one amplifier is overloaded and its summing point is at a high potential with respect to ground.

3. An overload indication occurs at each computing position when that position overloads and at a master position when any amplifier overloads. The indicators, triggered, stay ignited until manually reset.

To the author's knowledge, a combination of high stabilization gain and no crosstalk has previously not been attained. Furthermore, this paper describes the first multichannel system with an overload indication that remains ignited after being triggered. The usefulness of this feature in finding and correcting overloads has been demonstrated during operation of the computer at the DACL. This overload system is also useful in preventing dielectric absorption in the stabilization filter capacitors and input coupling capacitor, and in reducing overload recovery time.

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Combined Analogue and Digital Computing Techniques for the Solution of Differential Equations

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ONE of the difficulties in the use of an analogue computer for the solution of ordinary differential equations involving variable coefficients is its relative inability to perform certain multiplications rapidly and accurately. In instances where variables must be multiplied by a function of another variable, this difficulty is particularly apparent. This paper describes how a digitally stored table of functions may be used with an analogue computer to solve this general class of ordinary differential equations.

In the preparation of the machine for the problem, the functions of the variables are read into a magnetic drum by employing conventional digital techniques. During operation, the analogue inputs are compared continuously with their digital equivalents that are on the drum, and the digital functions of the input are read and digitally stored between readings. Digital-analogue multipliers are used to multiply the digital output by the appropriate analogue output. The advantages of the computer are (1) the shortness of the machine-preparation time, (2) the operating speeds which are faster than those of electromechanical multipliers using potentiometers or resolvers, and (3) the accuracy which is greater than that obtainable with electronic multipliers and function generators.

Introduction

The first part of this paper discusses a few of the limitations of analogue computers used in the solution of ordinary differential equations. Next are described several types of digital computers which are designed to perform certain operations more efficiently than the equivalent group of analogue components. Finally a specific analogue-digital computer is described which is currently under development at the Dynamic Analysis and Control Laboratory of the Massachusetts Institute of Technology.

Limitations of Analogue Computers

Analogue computers are capable of performing certain mathematical operations with rapidity and high accuracy. Some of these operations are addition, subtraction, multiplication by a fixed coefficient, and integration with respect to time. In general these operations permit solutions to problems involving ordinary differential equations at speeds many times that of the physical system under study and with accuracies often more than adequate for engineering purposes.

A second class of operations performed on analogue computers which are either less accurate or have slower solution times is multiplications of two or more variables. In general, two methods are used for the multiplication of independent variables. One is the electronic multiplier which may have a useful bandwidth of several hundred cycles but long-time accuracies seldom better than 0.25 per cent. A second method of multiplication is the servomultiplier. This multiplier is capable of static accuracies better than ten times that obtainable with the electronic multiplier but one input variable is restricted to a band width of several cycles per second if good accuracy is to be maintained. In addition, there are limitations on the maximum rate of change of the input.

A third class of operations which are restricted both in accuracy or bandwidth is the generation and multiplication of function of a variable. Electronic function generators have approximately the same bandwidth as the electronic multipliers but long-time stabilities are seldom better than 0.25 per cent. Additional errors are introduced in approximating complex functions by a series of straight lines. As a result, the product of one variable by a function of a second variable using electronic multipliers and function generators may have static errors as large as 0.5 per cent.

Servomultipliers with tapped potentiometers may also be used to obtain prod-

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