It is basically a parallel, straight binary-to-analog converter. The system is quite adaptable to time sharing. The frequency source and individual pulse-train generators associated with one conversion may be common to as many conversions as may be required. The additional circuitry for additional conversions is the gates associated with each digit of the binary number to be converted, and the circuits needed to standardize the pulses. Time-sharing techniques can be used in applying several different binary inputs to their associated gate enable lines. Capacitor "memories" on these lines eliminates the need for individual registers to hold each binary input.

ACKNOWLEDGMENT

The conversion system described was developed on a company-sponsored airborne digital computer research project. The author also wishes to acknowledge the suggestions and encouragement given by T. Lode which led to the development of this technique.

Discussion

W. A. Erickson: What was used as a constant current source?
Mr. Glick: The constant current source used in this system was transistorized current source built for an analog computing system.

W. Hochwald (Autonetics): It is not clear how the accuracy is independent of clock frequency.
Mr. Glick: The reason the accuracy is not affected by clock frequency is because of the fact that we are extracting a period of time \( T \) in which we wish to produce a certain number of pulses. Now, the output we get will, of course, be a function of the number of pulses that we put into this time period \( T \) and the ratio of the time the current is on to the time the current is off. Since we gear this time period to our basic computer clock which says that the time period \( T \) can vary, but the number will remain the same and therefore, the average current produced will remain the same regardless of variation. If there is a discontinuity in frequency, there will be an error. However, low velocity changes in frequency will not affect the accuracy of the system.
Hence the entire computer can be drift-stabilized by this system.

The signal grid voltage of the dc amplifier is fed to a commutator contact through the input filter. The input filter removes signals that are synchronous with the commutator sampling rate; otherwise, these voltages would be synchronously rectified by the commutator and appear as offset in the dc amplifier. The voltage applied to the commutator contacts is sampled by the commutator input wiper and amplified by the negative-gain stabilizer amplifier. This amplified voltage is then sent through the output wiper to the output filter of the same dc amplifier. The output filter reduces the ripple resulting from the pulse voltages received from the commutator. The filtered voltage is applied to the balancing grid of the dc amplifier, where it acts to restore the dc balance of the amplifier.

The commutator, the stabilizer amplifier, and the input filter capacitor, C1, are located in the same A14 modular plug-in unit (see Fig. 3). The other components of the input filter, along with the output filter components, are located with the associated dc amplifier. In Fig. 3, the commutator switch end-bells have been removed to show the ease of cleaning the contacts.

 error-detection circuits

The commutator stabilizing system provides a convenient central point for originating signals indicating faulty operation anywhere in the computer. Almost all component failures affecting the operation cause abnormally large voltages at the signal grid of the associated dc amplifier unit. The resulting large pulse from the stabilizer amplifier triggers the warning indicators.

Three types of warning indicators are used in the A14 computer: 1) a master indicator, on the computer control panel, that shows faulty operation and which, if the operator desires, will stop the computer and hold all voltages; 2) an easily visible group indicator that signals the general location of the offending element; and 3) individual indicators that pinpoint the defective unit. For example, if a tube in one of the switched dc amplifiers in an electronic multiplier becomes defective and impairs the accuracy of the solution, the master indicator on the computer control console will light, the group indicator on the particular electronic multiplier modular unit will light, and the individual light for the defective multiplier amplifier will light.

individual indicators

The operation of the individual indicators can be understood with the aid of Fig. 4. The NE-2 neon lamp is connected to the input of the output filter of the dc amplifier with which the indicator is associated. Resistor R2 and capacitor C2 are the same as in Fig. 2.
The NE-2 lamp sets the threshold value at which a pulse from the stabilizer will turn on the indicator. The NE-51, mounted on the front panel, provides the visual indication. The low-impedance positive bias source is set at a value between the firing and extinguishing potentials of the NE-51, which must be selected for these potentials. A built-in selfchecking circuit tests the NE-51 lamps.

A voltage pulse that fires the NE-2 will also raise the voltage across the NE-51 to the firing voltage. Once the NE-51 is ignited, current from the bias supply maintains the ionization. Capacitor C3 and crystal diode 1N34 form a diode clamping network permitting operation on both positive and negative pulses from the commutator. The NE-51 thus provides a memory-type indication that remains until turned off by the operator. Reset is accomplished by inserting high resistance in series with the bias supply so the current is reduced below the value necessary to maintain ionization. All NE-51 lamps are extinguished simultaneously. High resistance may be left permanently in series with the bias supply if a nonmemory flashing-type indication is desired.

Group Indicator

The group indicator is activated by the individual indicator circuits. All the NE-51's in a given modular unit, instead of being connected directly to ground as shown for simplicity in Fig. 4, are connected to a transistor flip-flop circuit. The input impedance of this circuit is on the order of a few hundred ohms; thus the operation of the individual indicator circuits is not affected. The flip-flop circuit operates a relay controlling an incandescent light on the front panel. This light is easily visible from a distance. Fig. 5 shows the front panel of an electronic multiplier modular unit with individual and group indicators.

Master Indicator

The signal for the master indicator is derived from a small resistor in series with the bias supply for the individual indicators. When any NE-51 fires and draws current from the bias supply, the voltage across the resistor changes. Amplified, this voltage change operates a relay that energizes circuits controlling the master indicator lamp. At the operator's choice, the relay in addition will energize an audible alarm, and place the computer into "hold," stopping the problem solution.

Self-Checking Circuits

The stabilization system itself has two built-in selfchecking circuits. The first provides a continuous check on the operation of the commutator and stabilizer amplifier. A small dc voltage is applied to a contact of the input pole of the commutator. The resulting amplified positive output pulse is applied through a filter to the grid of a tube having a large, fixed negative bias. This pulse is normally sufficient to keep the tube conducting strongly. If the pulse is absent or reduced in value (commutator stopped, stabilizer amplifier gain reduced, etc.), the tube will be cut off. The resulting high plate voltage flashes a neon lamp through a relaxation oscillator circuit. The neon lamp gives visual indication on the stabilizer modular unit; at the same time, the master indicator is activated.

Improvements in A14 Stabilizer Reliability

Major factors affecting the reliability and operation of the A14 stabilization system, in approximate order of decreasing importance based on experience with previous computers using commutator stabilization, include: leakage between adjacent contacts on the commutator, phasing of the commutator, mechanical failure of the commutator, hum pickup, and capacitive cou-
pling between input and output sections of the commutator. Methods used to improve these factors will now be described.

Many of the items affecting reliability in the past were associated with the commutator itself, probably because the commutators used in the early computers were originally intended for telemetering applications. These applications required sharp edges on the switching pattern, with relatively short life being acceptable. These conditions are not applicable in drift stabilization systems where sharp transition from switch “off” to switch “on” is unimportant. Consequently, investigations were made, in association with the commutator manufacturer, of the proper design of a commutator for exclusive use in drift stabilization.

Leakage between adjacent input contacts on the commutator causes both cross talk between channels and reduced gain, while leakage between adjacent output contacts causes only reduced gain. The input-contact cross-talk effects are greatly reduced by the 100-k isolating resistors and are not a major problem. However, leakage can reduce the stabilization gain almost to zero, and this effect has been the principal source of stabilization system failure in the past.

Leakage between contacts is caused by the accumulation of carbon particles from the silver-graphite brushes of the wiper arms. Experimentation has shown that life can be improved by reducing the brush pressure against the contacts. This pressure, in the case of the commutators intended for telemetering use, was more than 15 ounces. Satisfactory switch action for use in the stabilization system can be obtained with brush pressures of just a few ounces.

Optimum service-free brush life requires a fairly careful control of brush pressure and composition for controlled release of carbon-wear particles. Release of some particles is essential for proper lubrication. However, the particles must be small and released slowly to delay the build-up between adjacent contacts. The actual wear on the brush is quite small, with the ultimate brush life, based on the wearing away of material only, probably being about 50,000 hours. The service-free life of the brush and commutator is, of course, much shorter because of the development of leakage. Tests indicate an average service-free life of 5000 hours for the present commutator. Investigations are being made of methods of continually removing the wear particles from the commutator (e.g., by use of an air scoop). If these methods are successful, the life of the commutator may be limited only by the ultimate life of the brush.

Ease in cleaning the switch contacts has been provided by designing the commutator to make the contacts accessible by merely removing a dust cover, as shown in Fig. 3. Cleaning can be completed in a few minutes without disturbing any of the commutator adjustments. The construction also facilitates the measurement, and hence the control, of brush pressure.

Both the phasing and leakage requirements on the commutator are reduced by the type of output filter used (Fig. 2). The output wiper is phased to always lead the input wiper. A signal is sent from the signal grid to the output filter contacts only when both input and output wipers are simultaneously contacting signal contacts (including the shorting time to the adjacent contact). This interval is the channel “on” time. The charging-time constant of C2 with the output impedance of the stabilizer amplifier is considerably less than the average channel “on” time. Thus variations in channel “on” time produced by phasing differences result in small changes in stabilizer gain. A change of 25 per cent in the “on” time results in a gain reduction of less than 4 per cent.

The rectification efficiency of the output circuit (the ratio of the dc voltage developed across C2 to the output pulse amplitude) would be nearly 100 per cent if it were not for R2. R2 lowers the rectification efficiency to about 20 per cent by tending to discharge C2. The gain of the stabilizer amplifier is increased by a factor of 5 to compensate for this lower efficiency. Also, the effects of commutator leakage resistance, which is essentially in parallel with R2, is somewhat reduced, and the higher amplifier gain is useful in the error-detection circuits. The stabilizer gain is still an order of magnitude less than that used in the GEDA L3 and N3 stabilizer amplifier in which the holding capacitor C2 is not used.

Mechanical failures of the motor and bearings used in the earlier commutator can also be largely ascribed to the use of components not necessarily intended for long life. With a commutator specifically designed for long life, these failures should be almost eliminated. Capacitive coupling problems are largely eliminated because the stabilizer amplifier gain has been reduced.

Hum pickup in the input circuitry results in low-frequency variations, on the order of magnitude of the
hum, in the output of the dc amplifier being stabilized. One of the principal hum components can be largely filtered out by placing C1 in the commutator instead of in the dc amplifier. This procedure reduces the effect of hum voltage induced in the loop from the dc amplifier signal grid to the commutator and back through the ground. Much more freedom in cable layout is thus afforded.

**System Reliability and Dependability**

The reliability and dependability of the A14 drift-stabilization and error-detection system can be discussed under three aspects: mean time to failure, per cent service, and dependability itself.

**Mean Time to Failure**

The reliability of any system is indicated by the length of time it will operate properly without a breakdown. Computation of the mean time to failure of the system, a commonly used index of the capability of equipment to resist failure, permits quantitative description. The mean time to failure, of course, yields no particular information regarding the time between any two successive failures. The latter time is a function of the time distribution of failures of each component.

In any discussion of drift-stabilizing systems, the question arises of the relative reliability of a commutator system vs a system using chopper-stabilized amplifiers. Table I lists major items required in the A14 commutator system, with mean time to failure of each.

**TABLE I**

**Components of Commutator Stabilizing System**

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Mean Time to Failure—(hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commutators</td>
<td>4</td>
<td>5,000</td>
</tr>
<tr>
<td>Tubes</td>
<td>12</td>
<td>15,000</td>
</tr>
<tr>
<td>Resistors (composition)</td>
<td>92</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Under load</td>
<td>2,670</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td>No load</td>
<td>1,326</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Capacitors</td>
<td>4</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Transformers</td>
<td>8</td>
<td>25,000</td>
</tr>
<tr>
<td>Selenium rectifiers</td>
<td>8</td>
<td>25,000</td>
</tr>
<tr>
<td>Transistors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon diodes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

System Mean Time to Failure = 194 hours

Table II gives similar data for one of the more reliable chopper-stabilized systems currently available. The quantities are those required in a fairly large-scale computer currently being fabricated by Goodyear Aircraft Corporation. This computer uses 329 dc amplifier channels. The transformers, selenium rectifiers, and transistors listed in Table I are required in the regulated dc filament supply for the first two tubes of the stabilizer amplifier. Values for tube life given in Table II are greater than in Table I since an ac amplifier is used in the chopper system. The mean-lives of all components except the commutator are based on data taken over a four-year period in Goodyear Aircraft's Dynamic Systems and Computation Laboratory, and on published data. Information on commutator life is given elsewhere in this paper.

**TABLE II**

**Components of Chopper-Stabilizing System**

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Mean Time to Failure—(hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choppers</td>
<td>165</td>
<td>10,000</td>
</tr>
<tr>
<td>Tubes</td>
<td>329</td>
<td>20,000</td>
</tr>
<tr>
<td>Resistors (composition)</td>
<td>987</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Under load</td>
<td>3,290</td>
<td>$2 \times 10^4$</td>
</tr>
<tr>
<td>No load</td>
<td>2,303</td>
<td>$10^4$</td>
</tr>
</tbody>
</table>

System Mean Time to Failure = 26.4 hours

**Per Cent Service**

By per cent service is meant the ratio of actual operating time to operating plus trouble-shooting and maintenance time. High per cent service is just as important as long failure-free life in computer applications, where equipment breakdowns may be annoying but do not affect safety or completion of a mission.

The A14 system is unusually well-suited for high per cent service because the operation of 83 stabilization channels can be checked simultaneously from one location. There is no need for individual checking of a number of chopper-stabilized amplifiers to determine the defective units. The shortest-lived component in the A14 system as shown in Table I is the commutator. However, the life figure given is that for failure due to switch leakage; the ultimate life is much longer. Cleaning of the contact plate requires just a few minutes. The built-in checking circuits show when cleaning is needed.

**Dependability**

The dependability of a system represents the confidence the operator can have that the system is operating properly at any particular time. The error-detecting circuits previously described give the operator assurance that the computing equipment is functioning at all times. Another paper describes the A14 problem analyzer system. This system gives the operator a check on the accuracy of his solution. Together, these systems should give the operator the highest confidence in the proper and accurate operation of the A14 computer.

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Footnotes:

155x711

CONCLUSION

Improvements in the A14 commutator system have produced a reliable method of drift stabilization that gives convenient indications of malfunction anywhere in the computer. The system offers high per cent service and high dependability. The writer would like to give acknowledgment to his following associates at Goodyear Aircraft Corporation: P. J. Hermann, R. Armstrong, and W. H. Byers for data used in calculating mean time to failure, and to C. D. Morrill and S. B. Yochelson for their fine cooperation.

Discussion

S. Rogers (Convair): Is it true that the A14 commutator system improvements are in mechanical features and accessory circuits rather than in the basic circuits, or is there new art here, too? Do you have available reports on your chopper, commutator, and tube failures and on your failure-record system?

Mr. Eddy: Partly yes and partly no. The commutator permits easier cleaning of the unit and also better control of the pressure. We have used improved bearings and better motors, necessary to improve the mechanical operations of the unit. The circuitry we have improved by decreasing the requirements on the commutator itself.

A New Method of Verifying Analog Computer Problems and Performances

WILLARD C. MEILANDER†

INTRODUCTION

During the past decade the electronic differential analyzer has become an effective research and development tool. Present techniques allow the computer user to translate nearly every conceivable physical system into computer wiring diagrams.

The analog computer ideally is a super slide rule, for while it is easily capable of arithmetic operations, its outstanding ability to handle integrodifferential operations is its most salient feature. The conventional slide rule has been accepted as a reliable device, but the differential analyzer has not been so universally received. In fact, one of the more difficult problems associated with differential analyzers is determining whether they are solving the desired mathematical relations. The obvious technique of point-to-point verification of the wiring diagram is far too time consuming to be practical for most problems; therefore, several necessarily cumbersome methods have been developed to ascertain when the computer is correctly wired for a given problem. Some of these methods, such as digital or analytic solution of a test case of the general problem, are very laborious and time consuming, and, if the analog solution of the test case does not agree with the analytic or digital solution, the location of the error or errors still is not known.

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† The scope of problems studied is not, of course, limited to physical problems. Much important work in economic and other nonphysical fields has been carried out with the differential analyzer.

The problem then is: How can the reliability of the electronic differential analyzer, a super slide rule, be made more comparable to that of its simpler predecessor?

In the early days of analog computer use, the problems were comparatively simple. The small number of amplifiers and computing elements employed for a given problem did not require an elaborate method for determining whether the correct hookup was made on the problem board or whether the elements of the computer were operating correctly. Today, analog computers are becoming larger and more complex. The number of elements used for a given problem may exceed several hundred. Checking the computer to determine that the components are operating satisfactorily and, more important, that the problem is correctly wired has become a bothersome task. Present techniques require a point-by-point check of all elements of the system with an ohmmeter or by visual observation, or both. Generally, after the problem board is wired by one operator, a second operator checks it visually and compares it with a block diagram of the desired wiring.

The individual scales of a slide rule are checked by matching the indexes correctly for a particular problem. The result is accepted without question. The differential analyzer can be checked in a similar manner by verifying each computing operation, including scale, and comparing the hookup with the desired wiring diagram directly with the desired mathematical relations. Once it has been established that the requested computations