AECU-3248

Physics

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

THIS MEMORANDUM IS NOT TO BE

AECU-3248

SERVO-STABILIZATION OF DRIFT IN WIDE-BAND D-C AMPLIFIERS

J. M. Simmons, Jr.

Photostat Price \$

4.80

Microfilm Price \$

2.70

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

ABSTRACT

This report describes a method of diminishing the zero-drift characteristics of wide-band d-c amplifiers. The method is effective whether the amplifier is used with full open-loop gain or as a closed-loop computing element.

Case 416.00

April 13, 1954

UNCLASSIFIED

UNCLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DEFINITIONS OF SYMBOLS

WB-DC = wide-band direct-coupled amplifier

NB-DC = narrow-band direct-coupled amplifier

μ = open loop gain of WB-DC or NB-DC amplifier

μ_1 = gain of WB-DC major amplifier

μ_2 = gain of WB-DC used as stabilizing amplifier

μ_3 = gain of NB-DC chopper stabilizing amplifier

G = open loop gain of complete drift stabilized unit

$G_{DC} = \frac{\beta_1}{\beta_2 \beta_3}$ = d-c gain determined by drift stabilizing feedback network

A = closed-loop operational amplifier gain

Z = impedance

R = impedance which is generally entirely resistive

β = forward or feedback transmission factors determined by circuit impedances

T_c = time-constant of chopper amplifier

e_i = input voltage

e_o = output voltage

e_{co} = chopper amplifier output voltage

e_{os} = signal component of output voltage

e_{od} = drift component of output voltage

D_1 = equivalent input-grid drift voltage of μ_1

D_2 = equivalent input-grid drift voltage of μ_2

48 602

SERVO-STABILIZATION OF DRIFT IN WIDE BAND D-C AMPLIFIERS

One of the major errors of wide-band direct-coupled amplifiers has been entitled "zero-drift". The term "zero-drift" refers to the change in output voltage of the amplifier, which is caused by changes in absolute value of any or all internal components of the amplifier when the amplifier input voltage is made zero or at least held constant (zero change in input voltage). The output voltage of a direct-coupled amplifier is dependent upon the absolute value of every individual component in the amplifier as well as the input voltage and, since there is no known method of simply and rapidly determining the direction and magnitude of the undesirable changes of all internal components which may cause the output to drift, the output drift voltage must be considered as, and cannot be differentiated from, an equivalent input signal (drift) voltage. However, this equivalent input signal drift component does not actually occur on the input grid. This report proposes a method of comparing the actual input grid voltage with a portion of the output voltage in a comparator circuit which separates and amplifies only the undesirable "drift" component of the output voltage. This amplified "drift" component is used in a simple servo or regulator degenerative loop to partially compensate the original cause of the output "drift". Further analysis shows that the wide-band direct-coupled amplifier must be operated within its linear range (constant gain) in order to obtain full advantage of this method of decreasing zero-drift.

If the gain μ_1 of the wide-band direct-coupled amplifier remains constant, it is possible to decrease the equivalent input-grid drift of the wide-band d-c amplifier by a factor of $\mu_2/3$ to $\mu_2/2$ (almost to μ_2 by special design) where μ_2 is

the gain of the chopper (drift stabilizing) d-c amplifier (drift of chopper amplifier assumed zero) and also eliminate the undesirable side-effect of storage phenomenon in the chopper d-c amplifier.

Previous Work

A study of the obtainable limits of drift stability that may be realized in d-c amplifiers has been published by Mr. Verhagen⁽¹⁾. His paper deals with balancing methods and negative feedback involving only one stage. Mr. Verhagen's article leads to the logical, and well known, conclusion that a completely driftless d-c amplifier cannot be built with present-day electronic components although certain balancing and single-stage feedback techniques may reduce or minimize the drift. In certain applications this limit of minimum drift causes errors which are intolerable.

Mr. Goldberg⁽²⁾ has written a discussion of the practical use of chopper amplifiers for increasing the d-c gain and stability of wide-band d-c amplifiers when used as feedback amplifiers in analog computing elements. His article describes a method of decreasing the zero-drift of wide-band direct-current amplifiers when used in negative feedback computing circuits. Mr. Goldberg's article shows that his method of stabilization increases the total open-loop d-c gain of his circuit to $\mu_1\mu_2$, where μ_1 is the WB-DC amplifier gain and μ_2 is the chopper amplifier gain, and that drift is reduced approximately by the factor μ_2 when feedback is applied around the complete circuit as in an analog-inverter circuit. Feedback must be applied around Goldberg's circuit in order to realize any gain stability. See Fig. 1 in which the conventional method of negative feedback is employed to set G at some desired value. Assume that $\mu_1 = 1000$ and $\mu_2 = 1000$ and an open loop gain of $G = 1000$ is desired. Thus for $G = 1000$, $\frac{R_1}{R_2} = \mu_2$ and $R_1 = 1000 R_2$. Since R_2

appears as the equivalent input impedance its value should be as high as possible. If R_2 is 1 megohm, which is in general lower than desirable, it is seen that R_1 must be 1000 megohms which is clearly unpractical from a stability standpoint at the present time.

Fig. 1

It might be stated here that without feedback, as shown in Fig. 1, the output drift is not improved by addition of the chopper although the overall d-c gain is increased by μ_2 . Also it must be remembered that the full gain of $\mu_1 \mu_2$ is not realized for fast pulses ($G_{HF} \approx \mu_1$) but is realized only at d-c or at least after a time much greater than T_c where T_c is the time constant of the chopper amplifier. The chopper amplifier output voltage $e_{c o}$ can follow the input voltage only very slowly due to the long time constant T_c of the chopper amplifier which is generally from 1 to 25 seconds. This time constant acts as a filter and a storage device. The storage effects of T_c will cause an error ("time-constant error")

486 005

in e_o , the output voltage of the wide-band direct-coupled amplifier, if the d-c component of e_i changes faster than the time constant T_c of the chopper amplifier. Thus, it is seen that the chopper amplifier creates a "time-constant error" which in certain cases might exceed the improvement in error due to reduction of drift. This time-constant error for fast rise-time pulses is inherent in the design of the circuit of Fig. 1.

The Basic Drift Servo-Stabilizer Circuit

The circuit to be described in this report is capable of eliminating the time-constant error completely under prescribed conditions and is capable of drift-stabilizing open-loop gain, utilizing available components, without radically lowering the input impedance of the amplifier.

The basic principle of operation of the drift servo-stabilizer circuit depends upon the comparison of a percentage of the input voltage with a percentage of the output voltage. Internal amplifier drift appears as an output signal, from the comparator, which is amplified by a drift stable d-c chopper amplifier and then inserted into the differential stage of the wide-band d-c amplifier to partially counteract the initial drift.

A partial block diagram of the circuit is shown below.

Fig. 2

486 006

A complete block diagram, to be used for analysis, is shown in Fig. 3.

Fig. 3

Fig. 4 shows signal-flow graphs⁽³⁾ for the analytic condensation of Fig. 3.

Fig. 4(a)

Fig. 4(b)

Fig. 4(c)

Fig. 4(c) is completely described by Eq. 1;

$$e_o = -\mu_1 \left[\frac{e_i(1 + \beta_1\mu_2) + D_1 + D_2\mu_2}{1 + \mu_1\mu_2\beta_2\beta_3} \right] \quad (1)$$

Equation 1 is composed of the signal component

$$e_{o_s} = -\mu_1 e_{i_s} \left[\frac{1 + \beta_1\mu_2}{1 + \mu_1\mu_2\beta_2\beta_3} \right] \quad (2)$$

and the drift component

$$e_{o_d} = -\mu_1 \left[\frac{D_1 + D_2\mu_2}{1 + \mu_1\mu_2\beta_2\beta_3} \right]. \quad (3)$$

Let R_1 include the generator impedance Z_G . To obtain values for the most general set-up procedure, it is seen from Eq. (2), that β_1 should equal $\mu_1\beta_2\beta_3$ or

$$\beta_1 = \mu_1\beta_2\beta_3, \quad (4)$$

where, in general, $1/2 \leq \beta_1 < 1$ if $Z_{in_c} = \infty$ (Z_{in_c} = input impedance of chopper) and β_1 should always be greater than 0.33. Under the above conditions Eq. (2) reduces to

$$e_{o_s} = -\mu_1 e_{i_s} \left(\frac{1 + \beta_1\mu_2}{1 + \mu_1\mu_2\beta_2\beta_3} \right) = -\mu_1 e_{i_s} \quad (5)$$

486 008

and Eq. (3) reduces to

$$e_{od} = - \left[\frac{D_1}{\mu_2 \beta_2 \beta_3} + \frac{D_2}{\beta_2 \beta_3} \right] = - \left[D_1 \left(\frac{\mu_1}{\mu_2 \beta_1} \right) + D_2 \left(\frac{\mu_1}{\beta_1} \right) \right] \quad (4)$$

Equations (5) and (6) show that the open loop gain of the wide band d-c amplifier is not affected by the drift-stabilizing comparator circuit and that if $D_2 = 0$ (no zero-drift of the chopper) then the wide-band d-c amplifier equivalent input grid drift is reduced by the factor $\frac{1}{\mu_2 \beta_1}$.

If only long time drift stability is desired then a narrow band d-c chopper type amplifier with negligible drift may be used. Equation (6) also shows that the major part of the output drift voltage will be due to drift D_2 of the stabilizing chopper amplifier.

COMPONENTS USED AND TESTS

Two wide-band d-c amplifiers and one narrow-band chopper type d-c amplifier were used to actually construct the basic circuit shown in Fig. 2. Measurements were first made to determine the actual individual characteristics of these three amplifiers. Succeeding measurements were made in order to determine the practical feasibility of the drift servo-stabilizer circuit shown in block diagram form in Fig. 2.

Two wide-band d-c amplifiers, designated μ_1 and μ_2 , were designed and built following the diagrams given in Figs. 5 and 6. The helipot units used in Figs. 5 and 6 for zero setting of the output voltage of μ_1 and μ_2 were ten turn linear potentiometers with dials graduated from 0 to 1000 helipot units. Thus, 100 helipot units correspond to $100/1000 = 0.1$ of the total resistance of the helipot.

A chopper amplifier, designated μ_3 , out of a Reeves Computing Amplifier was used for tests which required a very low drift amplifier. Its diagram is shown in Fig. 7.

466 009

OFFICIAL USE ONLY

486 010

10

Wide-band Direct-coupled Amplifier - μ_1

Fig. 5

OFFICIAL USE ONLY

Wide-band Direct-coupled Amplifier with Positive Feedback - μ_2

Fig. 6

486 011

12

Reeves Chopper Amplifier - μ_3

Fig. 7

OFFICIAL USE ONLY

OFFICIAL USE ONLY

486 012

Test Results on Components

In order to determine the feasibility of the circuit shown in Fig. 2, Eq. (2) and Eq. (3) show that it was necessary to determine the gain of each amplifier and the equivalent input grid voltage drift generated per helipot unit. It was necessary to determine the approximate input impedance of the amplifiers in order to calculate the β_1 and the β_3 factors.

The following individual characteristics of the amplifiers were determined by measurement. It was found that the characteristics of μ_1 and μ_2 changed slightly with time but these changes occurred much slower than the time required for the tests and satisfactory test data were obtained.

μ_1 D-C gain = 450

$$D_1 = + e_{i_{d_1}} = - 51.1 \text{ mv. (100 helipot units).} \quad (7)$$

$$Z_{in_{\mu_1}} \approx \infty; \quad \text{zero} \approx 880 \text{ (helipot dial reading)}$$

μ_2 D-C gain = 530

$$D_2 = + e_{i_{d_2}} = - 42.4 \text{ mv. (100 helipot units).} \quad (8)$$

$$Z_{in_{\mu_2}} \approx \infty; \quad \text{zero} \approx 450 \text{ (helipot dial reading)}$$

μ_3 D-C gain = 1716

drift too low to be measured

$$Z_{in} = 3.17 \text{ megohms}$$

Tests on Stabilizing Circuit

The basic circuit shown in Fig. 2 was constructed utilizing the two wide-band d-c amplifiers in order to prove that the circuit was stable and that the output drift caused by drift of the stabilizing amplifier was not a function of the gain of the stabilizing amplifier.

486 013

The circuit used for test No. 1 is shown in Fig. 8.

Fig. 8

Test 1a: μ_1 gain = 450 μ_2 gain = 530
 Change μ_2 helipot setting + 100 units creating
 $D_2 = -42.4$ mv drift,
 $e_{od_2} = +38$ volts

Test 1b: μ_1 gain = 450 μ_2 gain = 2800
 $D_2 = -42.4$ mv
 $e_{od_2} = +38$ volts

The chopper d-c amplifier was used in Test No. 2, to drift stabilize the wide-band d-c amplifier in order to prove that the amount of drift reduction was proportional to the gain of the chopper stabilizing amplifier.

Test No. 2 was made with the chopper amplifier μ_3 as shown in Fig. 9.

Test 2a: μ_1 gain = 450 μ_3 gain = 1716
 $D_1 = e_{id_1} = 0.511$ volts, e_{od_1} (measured) = -0.34 volts.

486 014

Test 2b: μ_1 gain = 450, μ_3 gain = 484, (drift characteristics of μ_1 changed)

$$D_1 = e_{i_{d_1}} = 0.554 \text{ volts, } e_{o_{d_1}} \text{ (measured)} = -1.38 \text{ volts.}$$

Fig. 9

ANALYSIS OF TESTS ON STABILIZING CIRCUIT

Equation (3) may be used to determine the theoretical drift which should have been found in Tests No. 1 and Tests No. 2. The values of output drift computed from Eq. (3) are compared with the values measured in Tests No. 1 and No. 2.

Test 1a: D_1 assumed zero

$$D_2 = 0.0424 \text{ volts}$$

$$\beta_1 = \beta_3 = 1/2, \beta_2 = 1/450$$

$$e_{o_{d_2}} \approx - \frac{D_2}{\beta_2 \beta_3} = \frac{0.0424}{1/900} = +38.16 \text{ volts, against measured } +38.0 \text{ v. (9)}$$

Test 1b: Since μ_2 cancels out of Eq. (3),

$$e_{o_{d_2}} = +38.16 \text{ volts. (10)}$$

This test was run merely to prove that μ_2 gain had no effect on output drift D_2 due to μ_2 amplifier.

486 015

Test 2a: D_2 assumed zero

With chopper input impedance $Z_{in_c} = 3.17 \text{ Meg}$

$$\beta_1 = \beta_3 = 0.377, \beta_2 = 1/450, \mu_1 = 450, \mu_3 = 1716$$

$$D_1 = 0.511 \text{ volts}$$

$$e_{o_{d_1}} = - \frac{D_1}{\mu_3 \beta_2 \beta_3} = \frac{-0.511}{(1716)(1/450)(0.377)} = \frac{-0.511}{1.43762} = -0.355 \text{ v.} \quad (11)$$

against measured - 0.34 volts.

Test 2b: D_2 assumed zero

$$\beta_1 = \beta_3 = 0.377, \beta_2 = 1/450, \mu_1 = 450, \mu_3 = 484$$

$$D_1 = 0.554 \text{ volts (characteristics of } \mu_1 \text{ changed)}$$

$$e_{o_{d_1}} = - \left[\frac{D_1}{\mu_3 \beta_2 \beta_3} \right] = - \frac{0.554}{484 (1/450) (0.377)} = \frac{0.554}{0.4054844} = -1.37 \text{ v.} \quad (12)$$

against measured - 1.38 volts.

Discussion of Analysis Results

The preceding tests and analyses indicate that the stabilization circuit is a practical method of decreasing open-loop drift of a d-c amplifier and that Eq. (1) completely describes the characteristics of the system, neglecting varying input grid current.

There are some factors in Eq. (3) which merit more discussion since the utilization of the full merits of this system depend upon their stability. However, it is beyond the scope of this report to discuss methods of stabilizing these individual factors.

Assuming $\mu_1 \gg 1$ and $\mu_2 \gg 1$, Eq. (2) shows that the overall gain of the stabilized circuit is

$$G_{DC} = \frac{\beta_1}{\beta_2 \beta_3} \quad (13)$$

In general, β_1 and β_3 will be equal and β_2 will equal $\frac{1}{\mu_1}$ so that $G_{DC} = \mu_1$.

The high frequency gain $G_{HF} = \mu_1$ for any value of μ_1 or $\frac{\beta_1}{\beta_2\beta_3} = G_{DC}$.

If μ_1 is not equal to G_{DC} , part of the actual gain $G_{DC} = \frac{\beta_1}{\beta_2\beta_3}$ will be caused by a utilization of the gain μ_2 with its long time constant.

If a step function is impressed on e_i for a time longer than T_c so that full gain $G_{DC} = \frac{\beta_1}{\beta_2\beta_3}$ is realized from the circuit, then e_o will appear as a perfect step function as shown by the line in Fig. 10(a) if $\mu_1 = G_{DC}$. If $\mu_1 = \frac{G_{DC}}{2}$, then e_o will appear with a time-constant error as shown by the line in Fig. 10(b). This may be shown by the following analysis.

Let e_c = output voltage of the chopper, then

$$e_o = -\mu_1 (e_i - e_c), \quad t = \text{any value} > 0 \quad (14)$$

$$e_c = -\mu_2 (\beta_1 e_1 + \beta_2 \beta_3 e_o) \text{ for } t \gg T_c \quad (15)$$

Solution of Eq. (14) and (15) for e_c ($t \gg T_c$) gives

$$\begin{aligned} e_c &= -\mu_2 (\beta_1 e_1 - \beta_2 \beta_3 \mu_1 e_i + \beta_2 \beta_3 \mu_1 e_c) \\ e_c (\mu_1 \mu_2 \beta_2 \beta_3 + 1) &= -\mu_2 e_i (\beta_1 - \beta_2 \beta_3 \mu_1) \\ e_c &= -e_i \frac{\mu_2 (\beta_1 - \beta_2 \beta_3 \mu_1)}{\mu_1 \mu_2 \beta_2 \beta_3 + 1} \approx -e_i \frac{(\beta_1 - \beta_2 \beta_3 \mu_1)}{\mu_1 \beta_2 \beta_3} \end{aligned} \quad (16)$$

Let

$$e_{o1} = -e_i \frac{\beta_1}{\beta_2 \beta_3} \text{ at } t_f^- \quad (17)$$

where full gain $G_{DC} = \frac{\beta_1}{\beta_2 \beta_3}$ is realized. Also from Eq. (16), at t_f^-

$$e_i = -\frac{e_c \mu_1 \beta_2 \beta_3}{(\beta_1 - \beta_2 \beta_3 \mu_1)} \quad (18)$$

$$e_i = 0 \text{ at } t_f^+$$

$$e_{o2} = e_c \mu_1, \quad (19)$$

486 017

and the maximum error $\epsilon(t_f^+) = \left| \frac{e_{o2}}{e_{o1}} \right|$ (20)

becomes

$$\epsilon = \left| \frac{\frac{e_o \mu_1}{\beta_1}}{\frac{e_i}{\beta_2 \beta_3}} \right| = \left| \frac{(\beta_1 - \beta_2 \beta_3 \mu_1)}{\beta_1} \right|$$

$$\epsilon = \left| 1 - \frac{\beta_2 \beta_3 \mu_1}{\beta_1} \right| = \left| 1 - \frac{\mu_1}{G_{DC}} \right| = \left| \frac{G_{DC} - \mu_1}{G_{DC}} \right| \quad (21)$$

or $\% \epsilon$ = per cent change in gain of μ_1 from G_{DC} . Assume μ_1 decreases to $0.5 G_{DC}$. Then for a step-function input e_o is shown by the line in Fig. 10(b),

Fig. 10

and if $\mu_1 = \frac{\beta_1}{\beta_2 \beta_3}$ then the output e_o is a perfect step as shown by the line in Fig. 10(a). T_c is the long time constant of the chopper and μ_1 is considered to have infinite frequency response, i.e., $T_{\mu_1} = 0$. The gain of μ_1 should be maintained very constant at value $\mu_1 = \frac{\beta_1}{\beta_2 \beta_3}$ in order to minimize time constant errors occurring because of the long time constant of μ_2 when long pulses of short rise and fall time are being amplified.

Analog Computer Applications

It may be shown by the following analysis, that the drift-stabilization is retained when the servo-drift-stabilized amplifier is used as a feedback computing element.

486 018

Fig. 11

Fig. 12

Fig. 12(b) gives the equation

$$e_o = -(e_i \beta_1 + D) \left(\frac{\mu}{1 + \mu \beta_2} \right), \quad (22)$$

If $e_i = 0$, then

$$e_{od} = -D \left(\frac{\mu}{1 + \mu \beta_2} \right) \approx -\frac{D}{\beta_2} = -D \left(\frac{1}{\frac{Z_1}{Z_1 + Z_2}} \right)$$

$$e_{od} = -D \left(\frac{Z_1 + Z_2}{Z_1} \right) = -D \left[1 + \left(\frac{Z_2}{Z_1} \right) \right] = -D[1 + A] \quad (23)$$

Equation (23) shows that the output drift is equal to the equivalent input-grid drift multiplied by a factor which is equal to one plus the closed-loop gain.

In the servo-drift-stabilized amplifier the open-loop gain is not changed but the equivalent input-grid drift becomes

$$D = \frac{D_1}{\mu_2 \beta_1} + \frac{D_2}{\beta_1} \quad [\text{from Eq. (6).}]$$

486 619

If it is assumed that $D_2 = 0$ (stabilizing amplifier free from drift), then the equivalent input-grid drift is reduced by the factor $\beta_1 \mu_2$. Thus, the preceding equations for closed-loop drift apply also to the servo-drift-stabilized amplifier where $D = \frac{D_{\mu_s}}{\beta_1 \mu_2}$ and D_{μ_s} is the equivalent input-grid drift of the open-loop unstabilized amplifier.

Therefore, $e_{od} = -\frac{D_{\mu_s}}{\beta_1 \mu_2} (1 + A)$ for the servo-drift-stabilized amplifier, where D_{μ_s} is the equivalent input-grid drift of the WB-DC amplifier and the drift-stabilizing amplifier has no drift. Thus, the method of stabilization can also be used on computing amplifiers and if $\mu_1 = \frac{\beta_1}{\beta_2 \beta_3}$ the long time constant of the stabilization amplifier will insert no time-constant errors. Goldberg's series method of chopper stabilization requires that chopper gain and its resultant time-constant errors must be tolerated since the gains of the WB-DC amplifier and the chopper amplifier multiply for direct current.

Also Goldberg's method of chopper stabilization requires direct feedback for its full stabilization potentialities to be realized. This means that in the conventional integrator circuit the circuit must integrate drift in order to correct for the drift and this action thus creates an output error in correcting drift error. A more complete analysis of the Goldberg circuit is beyond the scope of this report. The stabilizing circuit described in this report and the Goldberg circuit should give practically identical results for short time (far less than T_c) computer operations. The comparator unit which is composed of R_1 and R_2 ($R_4 < R_2$) in Fig. 2 will create some loss in e_1 , which appears in Eq. (3) as a decrease in the apparent drift stabilizing gain of μ_2 . This loss factor is equal to β_1 which may be as low as 0.33 or, with special design, it may approach 1 although it can never equal 1. In Goldberg's circuit the factor similar to β_1 is always equal to 1 so that the drift decreasing ability of Goldberg's circuit is better than that of

486 020

the drift-servo-stabilizer circuit by the factor $1/\beta_1$; however, Goldberg's circuit is not very adaptable to open-loop stabilization and time-constant errors must be involved when long step functions are encountered.

SUMMARY AND CONCLUSIONS

A method of stabilizing the drift of a wide-band direct-current amplifier by means of a narrow-band chopper type d-c amplifier without involving the time-constant errors associated with the long time-constant gain of the stabilizing amplifier has been described.

It has been shown by tests which confirmed the analysis that such a circuit could be used to drift stabilize the open-loop gain. The drift may be decreased by a factor of $\mu_2/3$ to almost μ_2 where μ_2 is the gain of the chopper drift stabilizing amplifier with no drift. Standard techniques of servomechanism design may be utilized in adjusting the frequency responses of the WB-DC amplifier and the chopper drift stabilizing amplifier in order to use this circuit as an analog computing element. It was also shown that the amount of stabilization obtained depended mostly upon the gain and inherent drift stability of the chopper or stabilizing amplifier and that the maximum per cent error of e_0 for a unit-step input voltage (at t_0^+) due to chopper time constant was equal to the percentage drift in μ_1 or the ratio $100 \left(\frac{G_{DC} - \mu_1}{G_{DC}} \right)$ where $G_{DC} = \frac{\beta_1}{\beta_2 \beta_3}$ is the initial gain and μ_1 is the gain for which the per cent error is being calculated.

J. M. SIMMONS, JR. - 5414-1

DISTRIBUTION:

L. G. Abraham, 5400
D. B. Shuster, 5220
T. S. Church, 5410-A
H. H. Patterson, 5410-B
E. L. Deeter, 5430
A. J. Max, 5223
J. P. Shoup, 5413
J. M. Simmons, Jr., 5414-1
G. Byrne, 1922-2 (2)

486 021

Case No. 416.00
April 13, 1954

BIBLIOGRAPHY

- (1) "A Survey of the Limits in D-C Amplification", C. M. Verhagen, Proc. IRE, May 1953, pp. 615-630.
- (2) "Stabilization of Wide-Band Direct-Current Amplifiers for Zero and Gain", Edwin A. Goldberg, RCA Review, June 1950, pp. 296-300.
- (3) "Feedback Theory - Some Properties of Signal Flow Graphs", Samuel J. Mason, Proc. IRE, Vol. 41 No. 9, Sept. 1953, pp. 1144-1156.

436 022

1-22

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK