N 69 22779

NASA TECHNICAL MEMORANDUM

NASA TM X-53803

March 26, 1969

NASA TM X-53803

AN ELECTRO-MECHANICAL DC VOLTAGE AMPLIFIER

By Chester R. Savelle, Jr.
Quality and Reliability Assurance Laboratory

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL MEMORANDUM TM X -53803

AN ELECTRO-MECHANICAL DC VOLTAGE AMPLIFIER

By

Chester R. Savelle, Jr.

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

ABSTRACT

This report describes a novel dc voltage amplifier which utilizes the principles of an electro-mechanical servo system to achieve an excellent gain stability. A description of the system and equations for design and error analysis are included.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER
TECHNICAL MEMORANDUM TM X-53803

AN ELECTRO-MECHANICAL DC VOLTAGE AMPLIFIER

By

CHESTER R. SAVELLE, JR. *

*This report was prepared by SPACO, Inc., for the Analytical Operations Division, Quality and Reliability Assurance Laboratory, George C. Marshall Space Flight Center, under Contract No. NAS8-20081.

TEST RESEARCH SECTION
APPLIED TECHNOLOGY BRANCH
ANALYTICAL OPERATIONS DIVISION
QUALITY AND RELIABILITY ASSURANCE LABORATORY

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM TM X-53803

AN ELECTRO-MECHANICAL DC VOLTAGE AMPLIFIER

SUMMARY

The system described herein is a novel device for amplifying low level dc voltages. The system can be of low cost relative to conventional amplifiers having equivalent stability.

The gain and stability of this system is primarily dependent upon the ratio and ratio stability of a voltage divider consisting of two series-connected resistors. Design and error analysis equations along with discussions of the various parts of the system are included in this report.

SECTION I. INTRODUCTION

This report describes an electro-mechanical dc voltage amplifier which has the feature of an ultra-stable amplification ratio. The amplifier was conceived and developed in support of studies being made on thermal gas flowmeters.

In the flowmeter studies, it was necessary to measure the outputs of five copper/constantan or five cromel/alumel thermocouples with a resolution of four significant figures. For various reasons, switching and readout devices suitable for thermocouple voltages were not readily available. To obtain switching and digital readout at higher voltage levels, five electronic dc amplifiers were tried, but the amplifier drift exceeded the thermocouple voltages so the data was useless. A gain of 1000 was sufficient to raise the thermocouple voltages to a level where switching and readout could be done at low voltage levels. The gain of 1000 must be fixed and ultra stable. To achieve this ultra-stable gain, the device described herein was conceived and developed. This device should have uses in other areas of dc amplification and the purpose of this report is to disseminate information.

SECTION II. DEVELOPMENT DISCUSSION

A. PURPOSE

The general purpose of the electro-mechanical dc voltage amplifier is to multiply or amplify, by a fixed ultra-stable ratio, a small dc voltage to a voltage of a higher level. This amplification will allow switching of the voltage at the higher level, permit readout with a much less sensitive voltmeter than is required by the lower level voltages, and achieve the other benefits of the higher level voltage.

B. PRINCIPLES OF OPERATION

The electro-mechanical circuits and principles of their operation are illustrated by Figure 1. The essential parts of the amplifier consist of:

(1) A dc voltage supply E_1 (preferably a ripple-free voltage supply).

(2) A switch S_1 (DPST).

(3) A potentiometer R_1.

(4) A voltage divider consisting of resistors R_2 and R_3.

(5) A standard chopper input servo amplifier (A), driving servo motor (M).

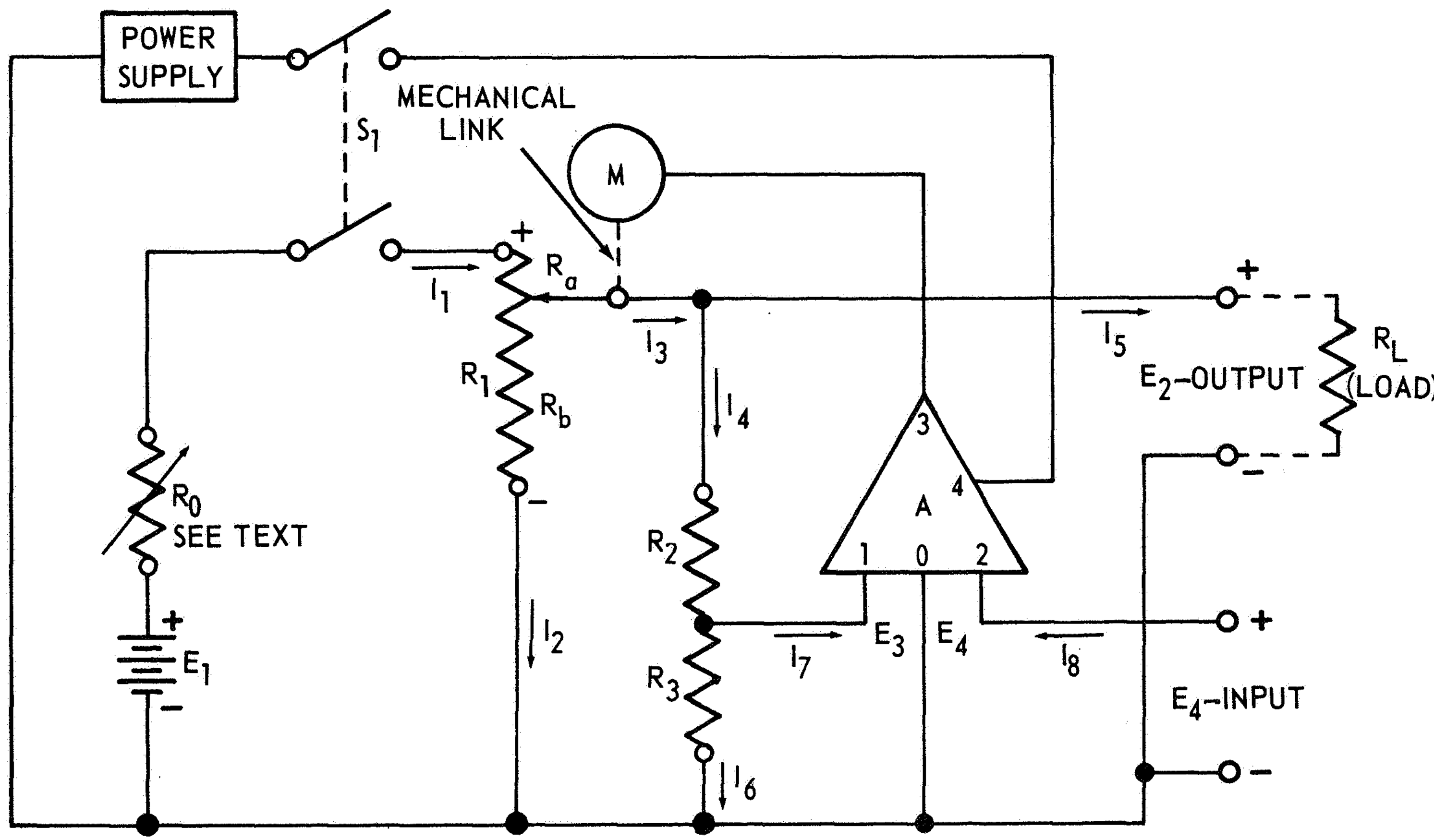
(6) A standard two-phase servo motor (M), mechanically linked to and driving potentiometer R_1.

(7) Input E_4 and output E_2 terminals.

An explanation of the operation of the amplifier system is given below. For the purpose of simplifying the explanation certain ideal conditions will be assumed as follows:

(1) Potentiometer R_1 has infinite resolution, and does not interact with R_L or $R_2 + R_3$.

(2) Voltage divider $R_2 + R_3$ has a perfect ratio.



ALL CIRCUITS SHOWN ARE ELECTRICAL EXCEPT AS NOTED

Figure 1. *Electro-Mechanical Circuits*

(3) The mechanical link between amplifier (A) and the R_1 output has no friction and has perfect damping.

Thus, with the assumed ideal conditions, the motor M will receive a drive voltage at any time there is the slightest difference in voltage between E_3 and E_4, and at exactly the time $E_3 = E_4$ the motor will stop without any overshoot. In a practical system, these ideal conditions may be approached but never attained. Later in this report is a discussion of the effects of the less than ideal conditions.

Given, for the moment, the ideal conditions discussed above, an explanation of the operation of the amplifier follows:

(1) The amplifier A has two dc inputs, No. 1 and No. 2, and the differential dc voltage between these two inputs is converted to an ac signal and amplified by some ratio and applied as a drive voltage to the servo motor M. The voltage conversion and amplification process is such that when a voltage at input No. 1 is positive (+) with respect to input No. 2, the servo motor M will drive the wiper of potentiometer R_1 toward the (-) end of the potentiometer. Conversely, if the voltage at input No. 2 is positive with respect to input No. 1, the potentiometer wiper will be driven toward the positive (+) end of the potentiometer. Thus far, the mode of operation is that of the standard servo positioning system where voltage E_4 is the positioning signal, and voltage E_3 is the feedback voltage indicating when the desired position has been reached. The insertion of the voltage divider R_2 and R_3 creates a nonstandard condition and converts the servo system from a positioning device to a voltage amplifying device.

(2) With switch S_1 closed, the servo amplifier A receives its excitation voltage and the dc voltage E_1 is applied across the potentiometer R_1. The voltage E_2 is a function of the wiper position along the resistance R_1 and may vary in amplitude from a value of 0 to a value equal to E_1. E_2 is the output voltage and is applied across voltage divider R_2 and R_3.

(3) A voltage applied to input E_4 will, by standard servo system operation, cause a potentiometer R_1 drive to raise or lower the amplitude of voltage E_3 to exactly the same amplitude as E_4. Since amplifier A amplifies only the differential between E_3 and E_4, no drive voltage will be applied to motor M when $E_3 = E_4$. The system will then be in a state of rest at some value for E_2 necessary to generate voltage $E_3 = E_4$.

(4) The relationship of the amplitudes of voltages E_2 and E_3 (E_3 developed at the junction of R_2 and R_3) is a function of the ratio of $R_3/(R_2 + R_3)$. Voltage $E_3/E_2 = R_3/(R_2 + R_3)$ or $E_3 = E_2 (R_3/(R_2 + R_3))$. Thus, voltages E_3 and E_2 have an exact fixed ratio between them.

(5) Since it has been shown that E_3 must always equal E_4 for the servo system to be at rest, it follows that E_4 is related to E_2 by the same ratio as E_3 is related to E_2. Thus, $E_4/E_2 = R_3/(R_2 + R_3)$ or $E_4 = E_2 (R_3/(R_2 + R_3))$, and $E_2 = E_4((R_2 + R_3)/R_3)$. $R_2 + R_3$ is always greater than R_3 and it follows that E_2 is always greater than $(E_3 = E_4)$, except the condition at zero when $E_2 = E_3 = E_4 = 0$.

(6) Since E_2 is greater than E_4 by a fixed ratio, amplification of E_4 by the ratio of $(R_2 + R_3)/R_3$ has been achieved by the system.

The preceding discussion has shown that the subject system is a dc voltage amplifier. In all of the discussion which follows, the term "amplifier" will be used to refer to subject system, and the term amplifier (A) will be used to refer to the servo amplifier (A) which is a part of subject system. It should be remembered that the input voltage is not amplified by amplifier (A). Actually, the input voltage is not amplified directly by the system. Instead, the system generates and controls an output voltage which is greater than the input voltage, and is directly proportional to the input voltage by a fixed ratio. Technically speaking, the system is not an amplifier but a controller. However, a definition of an amplifier might be a device in which the operation satisfies the equation:

$$E_{out} = E_{in} (K) \qquad K > 1$$

and, the operation of subject system does satisfy this equation. So, practically speaking, the system is an amplifier.

SECTION III. SYSTEM ANALYSIS

A. GENERAL

In the preceding discussion, certain ideal conditions were assumed to simplify the discussion. The same ideal conditions will be assumed in this section to derive the general equations for design of the system. To describe the system operation it will be necessary to use terms that are in addition to those shown in Figure 1. Definitions of these terms are as follows:

Term Definitions

V_m - Voltage output of amplifier (A)

V_s - Voltage required to start motor

V_r - Voltage required to keep motor running

E'_n - Maximum condition of schematic voltages with subscript n designating the particular voltage

G_s - Gain of amplifier system

G_A - Gain of servo amplifier (A)

R_{A1} - Impedance of amplifier (A) input No. 1

R_{A2} - Impedance of amplifier (A) input No. 2

The operation of the amplifier system is based on the operation principles of a closed loop servo system. The operation is shown in Figure 2. With an initial condition of $E_2 = E_3 = E_4 = 0$ and the mechanical link open between motor M and pot R_1, the system is at rest. If E_4 is then changed to a value $E_4 \neq E_3 = 0$, the amplifier (A) will amplify the $(E_4 - E_3)$ difference and apply voltage $V_m > V_s$ to motor (M) which will start and continue running until the mechanical loop is closed and $E_4 = E_3$.

B. OPEN LOOP OPERATION

Subsequent discussion of Equations (1) through (4) will be based on the condition of open loop operation.

1. Supply Voltage E_1. Since the E_1 voltage supplies the output voltage, the condition $E_1 \geq E_2'$ must exist and:

$$E_1 \geq E_2' = E_4' G_s, \tag{1}$$

where G_s is the desired amplification ratio for the system. If E_1 is much greater than $E_4' G_s$, the resolution of pot R_1 will be effectively reduced; so the value E_1 should be greater than but as near as possible to the voltage required by the desired amplification ratio. A battery is an ideal source for E_1 since it is ripple free, and the regulation of E_1 is not very critical as will be shown later. However, it may sometimes be difficult to obtain the exact battery voltage required, so variable resistor R_o can be inserted to adjust the voltage applied across R_1. Since regulation of E_1 is not critical, any adverse voltage effects as caused by R_o is not critical. For simplification of later discussion, it will be assumed that R_o is not used and E_1 is slightly greater than or equal to E_2'.

2. Voltage E_2. Voltage E_2 is a function of the position of the R_1 wiper along the resistor R_1. This position is defined by the ratio of R_a and R_b with $(R_2 + R_3) = R_D$ in parallel with R_b. R_L is not necessary at this time so $R_L = \infty$ and:

$$E_2 = E_1 \left(\frac{\dfrac{R_b (R_D)}{R_b + R_D}}{R_a + \dfrac{R_b (R_D)}{R_b + R_D}} \right)$$

which reduces to:

$$E_2 = E_1 \left(\frac{R_b (R_D)}{R_a (R_b + R_D) + R_b (R_D)} \right) \tag{2}$$

3. Voltage E_3. The voltage E_3 is related to voltage E_2 by the ratio of resistors R_2 and R_3:

$$E_3 = E_2 \left(\frac{R_3}{R_2 + R_3} \right) \qquad R_{A1} \gg R_3 \tag{3}$$

The input impedance of amplifier (A) would normally be at least 1×10^4 times greater than R_3 so R_{A1} will have an insignificant effect on the value of R_3. Thus R_{A1} is not included in the equation for E_3.

4. Motor Voltage V_m. The motor voltage V_m is supplied by amplifier (A) which has gain G_A. Gain G_A is a constant and is independent of the operation of the subject system. The motor voltage is amplified by amplifier (A) from the differential voltage between E_4 and E_3 which is the input to amplifier (A). The equation for V_m is:

$$V_m = (E_4 - E_3) \cdot G_A \tag{4}$$

C. CLOSED LOOP OPERATION

Thus far, only the condition of open loop operation has been considered and the system has produced no controlled amplification ratio. Subsequent discussion will consider closed loop operation.

In the preceding open loop discussion, the system condition was stated as $E_2 = E_3 = 0$. $E_4 > E_3$, and the motor was shown to be running. The direction of motor rotation was so that it would rotate pot R_1 in a direction to increase the value of E_2 from the initial condition $E_2 = 0$. As E_2 increases, E_3 is increasing by the ratio to E_2 as shown in Equation (3).

With closed loop operation, E_3 will continue to increase until $E_3 = E_4$ and $V_m = 0$, equation 4, and the motor stops. Controlled amplification by the system has been achieved.

System Gain - The system gain is the ratio of the system output E_2 to the input E_4. Let G_s be the system gain and:

$$G_s = \frac{E_2}{E_4}$$

E_2 is related to E_3 by the ratio

$$E_3 = E_2 \left(\frac{R_3}{R_2 + R_3} \right)$$

Let Q be the ratio $\frac{R_2 + R_3}{R_3}$ and:

$$E_3 = \frac{E_2}{Q}$$

While $V_m > 0$ the E_2 voltage is less than the E_2 voltage at the stable condition of $V_m = 0$.

From Equation (4):

$$V_m = E_4 G_A - E_3 G_A \qquad G_A = \text{Constant gain of (A)}$$

For:

$$V_m = 0, \; E_4 = E_3 = \frac{E_2}{Q}$$

$$G_s = \frac{E_2}{E_4} = \frac{E_2}{\frac{E_2}{Q}} = Q$$

$$G_s = \frac{R_2 + R_3}{R_3} \tag{5}$$

Therefore, the ideal system gain is solely dependent upon the ratio of R_2 and R_3. From the preceding equations the equation for less than ideal closed loop operation can be derived.

$$E_2 = E_4 G_s \pm \frac{V_m G_s}{G_A} \tag{6}$$

It can be seen that the term E_4G_s represents the ideal conditions of $V_m = 0$, whereas the term $\frac{V_m G_s}{G_A}$ represents system error or resolution under less than ideal conditions of $V_m \neq 0$. The term $\frac{V_m G_s}{G_A}$ may be (+) or (-) with respect to E_2 depending upon the relative amplitudes of E_3 and E_4 after an amplitude change of E_4 in which $(E_4 - E_3)\, G_A > \frac{V_m G_s}{G_A}$.
Thus, Equation (6) is the basic equation required for error analysis of the system.

SECTION IV. ERROR AND DRIFT ANALYSIS

A. MECHANICAL FRICTION

Thus far all discussion has been concerned with an ideal system in which there was no friction in the mechanical link between the amplifier (A) and the potentiometer output E_2. The system is described by Equation (6), and motor voltage V_m can be reduced to zero, thus eliminating the $\frac{V_m G_s}{G_A}$ term from the equation.

In a practical system friction will exist, and it is obvious that the term $\frac{V_m G_s}{G_A}$ represents the finite system resolution or error that will occur due to friction. The amplitude of the motor torque required to overcome the friction may be represented by a motor voltage V_m with an additional subscript to relate it to the type of friction. There are two types of friction that must be considered. The static friction (including inertia) must be overcome to start the motor running, and the dynamic friction must be overcome to keep the motor running. The starting voltage can be designated V_{ms} and the running voltage designated V_{mr}. It is characteristic that $V_{ms} > V_{mr}$, so that the appropriate value must be used when computing error or drift.

During discussion of errors in system output, it will be assumed that a previous E_4 or drift change has been large enough to start the motor running. Thus, the equations for error will use V_{mr}. Discussion of drift will assume that the system is at rest and the motor must be started, so equations for drift will use V_{ms}. Actually, since $V_{ms} > V_{mr}$, errors (ΔE_E) (error) and drift (ΔE_D) (drift) will always be related by the ratio V_{mr}/V_{ms}. Errors or drift in the output voltage E_2 are the ones of concern, so the terms ΔE_{2E} and ΔE_{2D} will be used to designate the amplitude of the respective changes in output. Equation (6) now becomes:

$$E_2 + \Delta E_2 = E_4 G_s + \frac{V_m G_s}{G_A} \qquad V_m \neq 0$$

Which is:

$$\Delta E_2 = \frac{V_m G_s}{G_A}$$

For Error:

$$\Delta E_{2E} = \frac{V_{mr} G_s}{G_A} \qquad (7)$$

For Drift:

$$\Delta E_{2D} = \frac{V_{ms} G_s}{G_A} \qquad (8)$$

It can be seen that the mechanical system friction factor $V_m \neq 0$, being present, is the reason why errors and drifts by other components of the system will affect the output. The exception to this is the factor G_s which is affected only by the voltage division ratio of R_2 and R_3.

B. VOLTAGE DIVIDER RATIO

The voltage divider R_2 and R_3 is the heart of the amplifier inasmuch as it sets and controls the amplification or gain ratio.

To determine the effects on the G_s ratio of errors in the values of E_2 and E_3, let G_s' be the value for gain other than ideal nominal, and K_n be the percent variation from nominal resistor values with the subscript n designating the associated resistor. From Equation (5):

$$G_s = \frac{R_2 + R_3}{R_3}$$

(R_2 and R_3 exactly nominal value)with K_2 and K_3 variations in R_2 and R_3:

$$G_s' - G_s = \frac{R_2 + K_2R_2 + R_3 + K_3R_3}{R_3 + K_3R_3} - \frac{R_2 + R_3}{R_3}$$

Which reduced to:

$$G_s' = \frac{R_2 (K_2 - K_3)}{R_3 (1 + K_3)} + G \qquad (9)$$

If the K_n variations of R_2 and R_3 are the same, then $K_2 = K_3$ and Equation(9) becomes:

$$G_s' = G$$

It can be seen from Equation (9) that the absolute values of R_2 and R_3 are not critical, but the ratio between the actual values of R_2 and R_3 is critical. Fortunately, the ratio between two resistor values can be measured and adjusted to a high degree of accuracy.

The resistor values will change as the temperature of the resistor changes. This resistor value change is expressed as a coefficient which is a percent change per degree of temperature change. To investigate the effects of temperature change let:

K_n = Temperature coefficient with n = associated resistor

T_n = Temperature change from nominal with n = associated resistor

G_s'' = Gain at temperature changes from nominal

The variations due to temperature will have exactly the same effect on the voltage divider as shown in Equation (9) and the resistor values are found by $R_n K_n T_n$ so:

$$G_s'' = \frac{R_2(K_2 T_2 - K_3 T_3)}{R_3 (1 + K_3 T_3)} + G_s \qquad (10)$$

If the K_2 and K_3 are controlled so that $K_2 = K_3$ and if the resistors are designed and installed so that $T_2 = T_3$, then Equation (10) becomes:

$$G_s'' = G_s$$

Thus it can be seen that with good design and fabrication, excellent accuracy and stability can be achieved for G_s which is the system amplification ratio.

C. VOLTAGE E_1

The effects of steady state variations in absolute value of E_1 can be determined by examining Equation (6). Voltage E_1 does not appear in this equation for closed loop operation, so the steady state absolute value of E_1 does not affect the output voltage E_2.

Drift in the value of E_1 will cause drift in E_2 up to the limit $\frac{\Delta E_2 G_A}{G_s} = V_{ms}$, where E_2 is drift caused by drift of E_1. Beyond this limit the motor will start and run until $\frac{\Delta E_2 G_A}{G_s} < V_{mr}$, and the drift in E_1 will have been corrected to a value within the system resolution. To investigate the effects of drift of E_1, Equations (2) and (6) may be used. It is evident from Equation (2) that $E_2 < E_1$ except when $R_a = 0$ in which case $E_2 = E_1$. If ΔE_1 is the drift in E_1, it can be shown with Equation (2) that drift $\Delta E_2 < \Delta E_1$, except when $R_a = 0$, so $E_2 = E_1$ and $\Delta E_2 = \Delta E_1$. Thus, the worst case for ΔE_1 effect on output E_2 is when $E_2 = E_1$ and the maximum E_2 drift due to E_1 is:

$$\Delta E_1 = \Delta E_2 = \frac{V_{ms} G_s}{G_A} \quad \text{(Max.)} \tag{11}$$

A condition for Equation (11) is that the rate of drift $\frac{\Delta E_1}{t}$ is not greater than the maximum possible rate of E_2 change as shown by $\frac{\Delta E_3}{t}$ in Figure 2.

D. POTENTIOMETER R_1

The potentiometer R_1 produces directly the output voltage E_2. At first glance it would seem that the characteristics of absolute resistance, linearity, and resolution would be critical for this system.

The effects of the absolute resistance can be examined by the use of Equation (2). If $R_b = 0$, $E_2 = 0$ and if $R_a = 0$, $R_2 = R_1$. All values for $0 < E_2 < E_1$ depend (within the limits of pot. resolution) only on the ratio of R_a and R_b, with a nonlinearity factor introduced by $R_2 + R_3$ parallel to R_b. Thus, the absolute resistance value for R_1 is not critical insofar as the adverse effects on output voltage E_2.

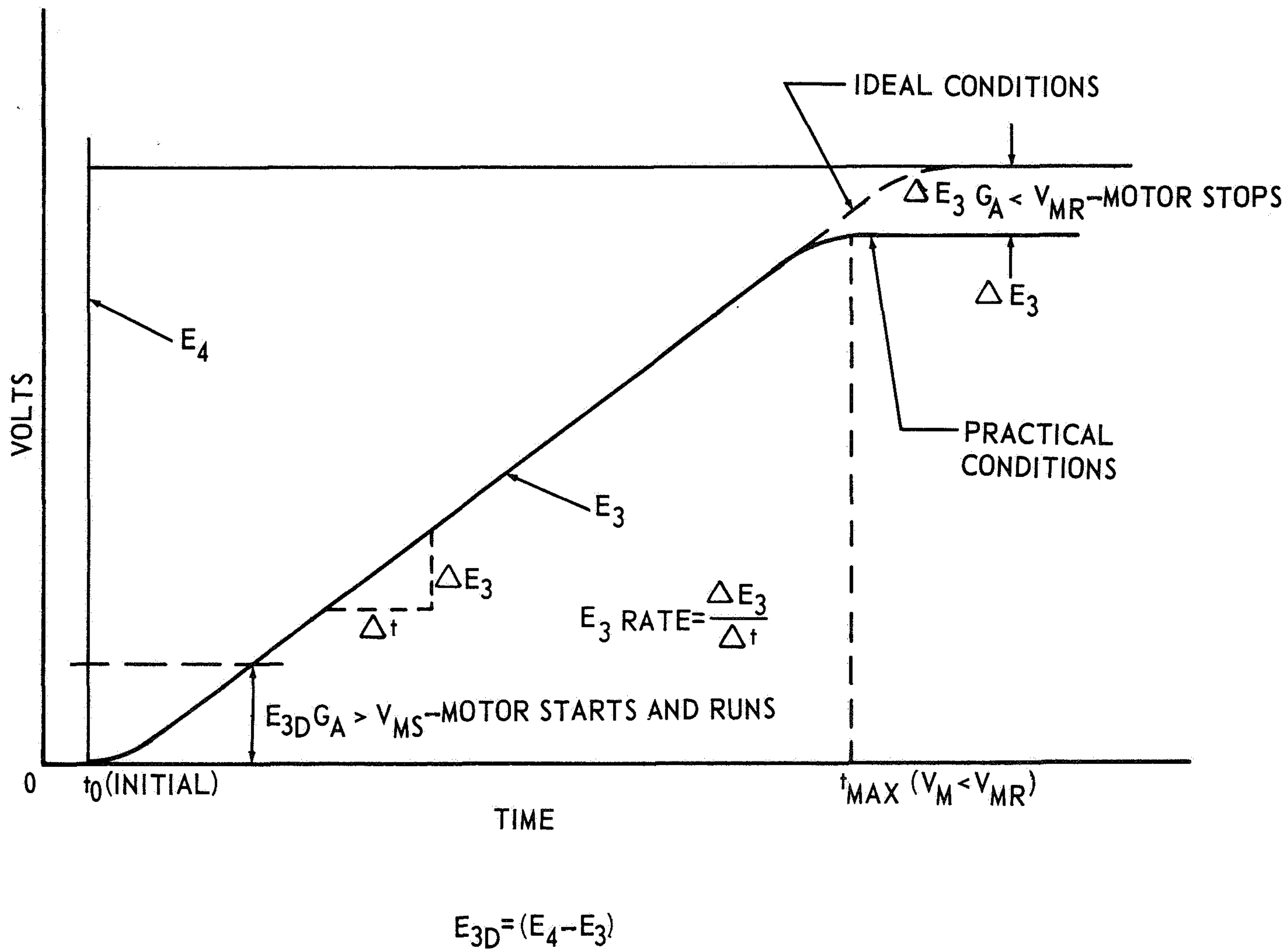


Figure 2. Practical System Operation

The effects of potentiometer nonlinearity can best be illustrated graphically as in Figure 3 with an exaggerated nonlinear condition shown by the E_3 voltage curve. From Equation (4):

$$V_{mr} = \Delta E_3 G_A \quad \text{where } \Delta E_3 = (E_4 - E_3)$$

If $\Delta E_3 G_A > V_{ms}$, the motor starts and must run until $\Delta E_3 G_A < V_{mr}$. As seen in Figure 3, nonlinearity of R_1 can only affect the time t_{BAL} at which $\Delta E_3 G_A < V_{mr}$ occurs. Thus, the linearity of potentiometer R_1 is not critical insofar as the adverse effects on output voltage E_2.

The resolution of the potentiometer has a direct effect on the output E_2 since the output is derived from R_1. The resolution is the number of parts (P) into which the voltage E_1 will be divided by the pot R_1. If ΔE_2 is the desired resolution of the output voltage:

$$\Delta E_2 = \frac{E_1}{P}$$

The pot. R_1, with finite resolution, is basically a step voltage generator as shown in Figure 4 which shows output voltage E_2 reduced to the E_3 values by the ratio G_s. At voltage $E_4(1)$, which can be any value of E_4 within the system range, is shown the condition that arises if the voltage steps are greater than the desired resolution of the system. The pot is at Step A and voltage $E_4(1)$ is at the worst condition level with respect to Step A and Step B:

$$\frac{E_1 G_A}{2PG_s} > V_{mr}$$

So, the motor continues to run until the Step B is reached. At this point:

$$\frac{-E_1 G_A}{2PG_s} > V_{mr} \quad \text{(180-degree phase shift in } V_{mr})$$

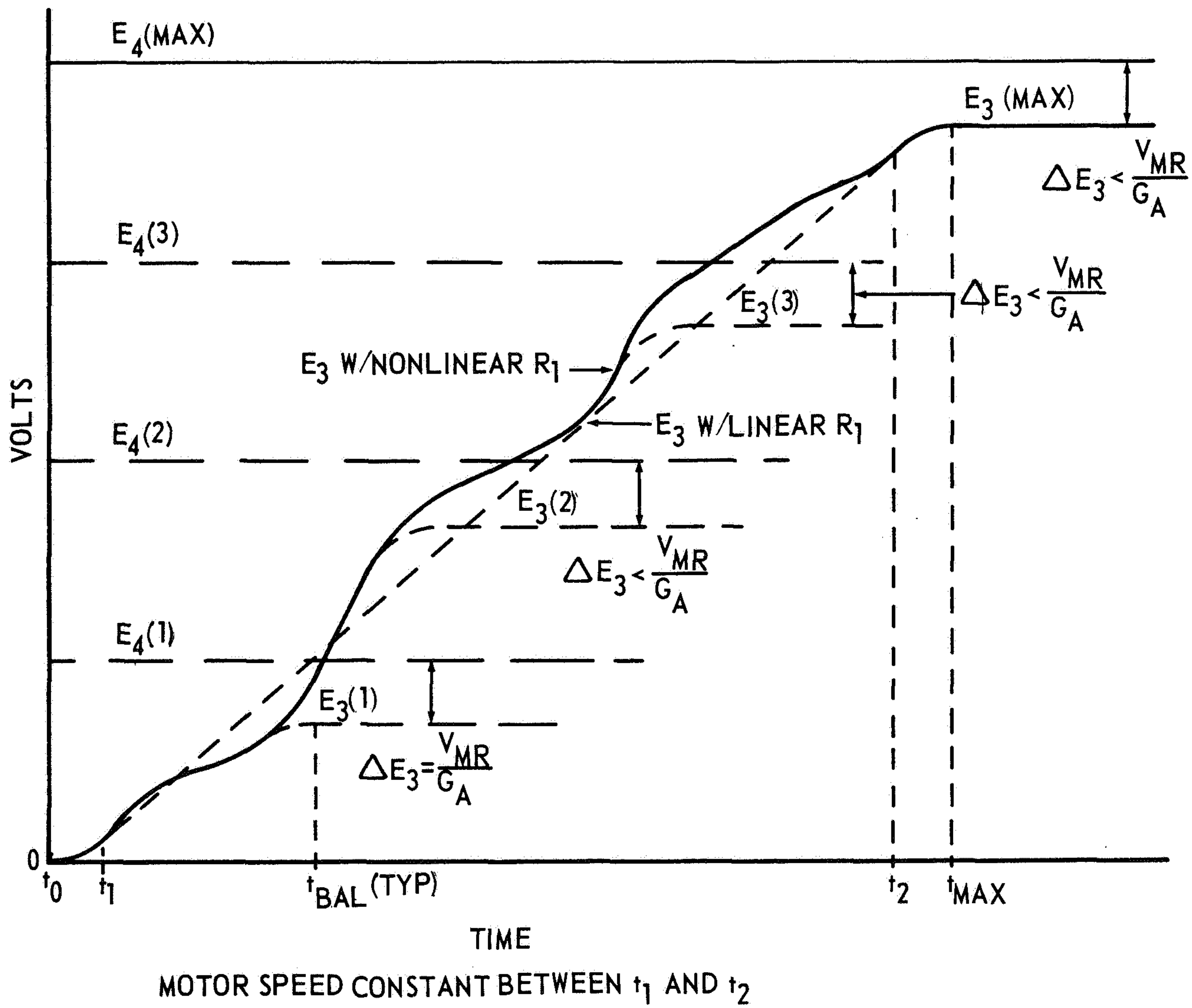


Figure 3. R_1 Nonlinearity

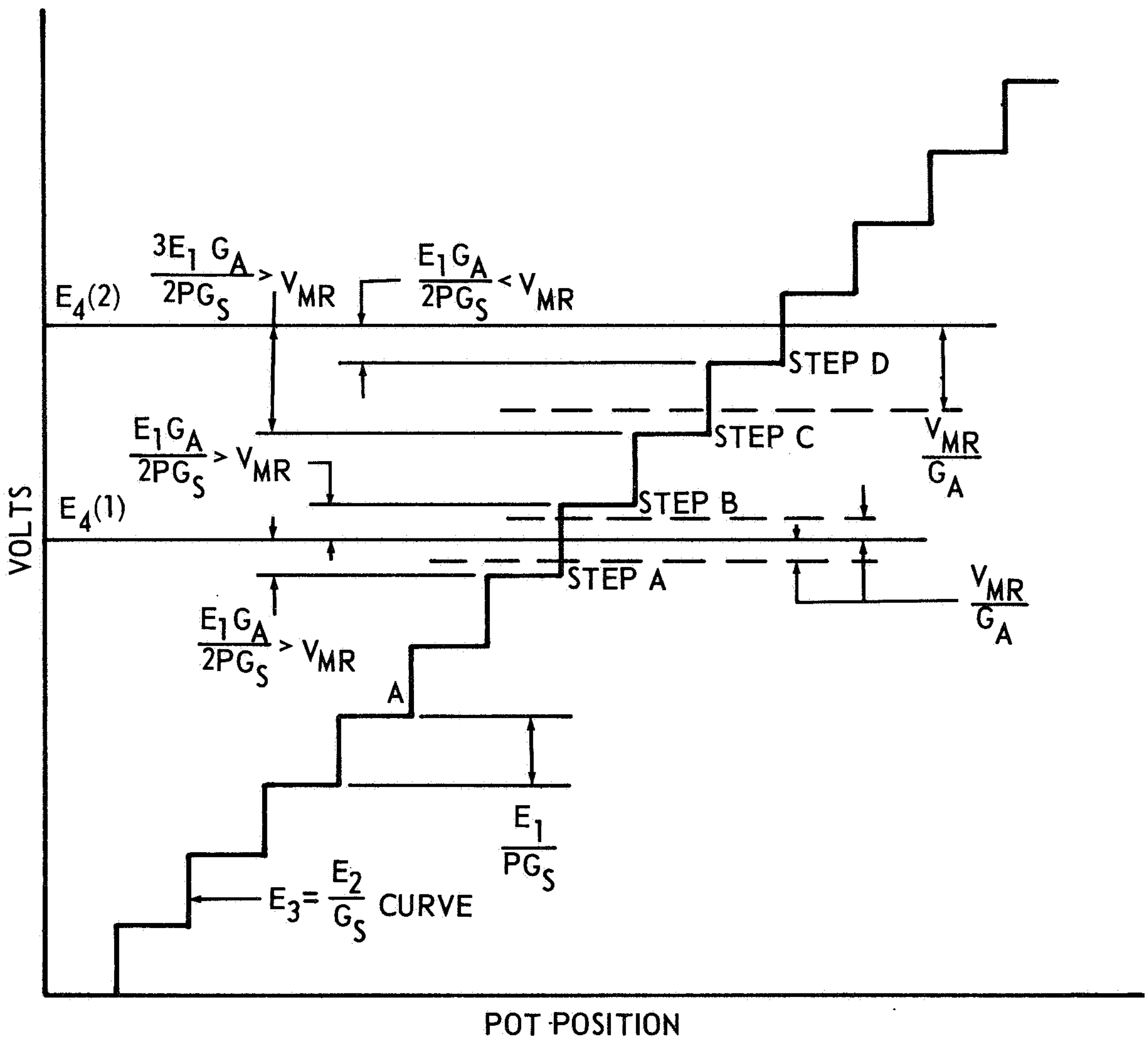


Figure 4. R_1 Resolution

So, the motor reverses and runs until Step A is again reached, when motor again reverses, etc. This is an unstable condition. At E_4 (2) is shown the condition when the voltage steps are less than the desired resolution of the system. The pot is at Step C where:

$$\frac{3E_1G_A}{2PG_s} > V_{mr}$$

So, the motor runs until Step D is reached. At this point:

$$\frac{E_1G_A}{2PG_s} < V_{mr}$$

and the motor stops. This is a stable condition. As a design condition let:

$$\frac{E_1}{P} \leq \frac{E_2}{A} \qquad \text{(A = arbitrary factor > 1)}$$

and since:

$$\Delta E_2 = \frac{V_{mr}G_s}{G_A}$$

$$P \leq \frac{A\, E_2' G_A}{V_{mr}G_s} \qquad (\text{if } E_1 = E_2 = E_4G_s) \qquad (12)$$

Equation (12) defines an R_1 resolution that makes it possible to achieve a desired system resolution. The equation also shows the detrimental effects of $E_1 \gg E_2'$ for if this condition exists, the required P will be greater.

E. AMPLIFIER (A)

One of the characteristics of subject system is the excellent stability of the amplification ratio which is not directly dependent upon the stability of the gain of amplifier (A). Errors or drift produced by drift in G_A may be determined by Equations (7) and (8):

$$\Delta E_{2E} = \frac{V_{mr} G_s}{G_A} \quad \text{(Error)}$$

$$\Delta E_{2D} = \frac{V_{ms} G_s}{G_A} \quad \text{(Drift)}$$

It is noted that ΔE_{2E} or ΔE_{2D}, as caused by ΔG_A, reduced by the factor G_s which is dependent only on the ratio of R_2 and R_3. If G_A is changed by a factor B, the error or drift in output E_2 is:

$$\Delta E_{2E} = \frac{V_{mr} G_s}{BG_A} \quad \text{(Error)}$$

$$\Delta E_{2D} = \frac{V_{ms} G_s}{BG_A} \quad \text{(Drift)}$$

or:

$$B = \frac{G_s \, (V_{m(r \text{ or } s)})}{G_A \, \Delta E_{2D}} \quad (\Delta E_{2D} = \text{allowable drift in } E_2) \qquad (13)$$

The drift factor B is always reduced by the factor G_s, and the drift in E_2 is proportional to the reduced drift factor B. Thus, an extremely stable G_A is not required. An amplifier (A) characteristic that is critical is the dc drift voltages that may occur in the input to the dc to ac converter.

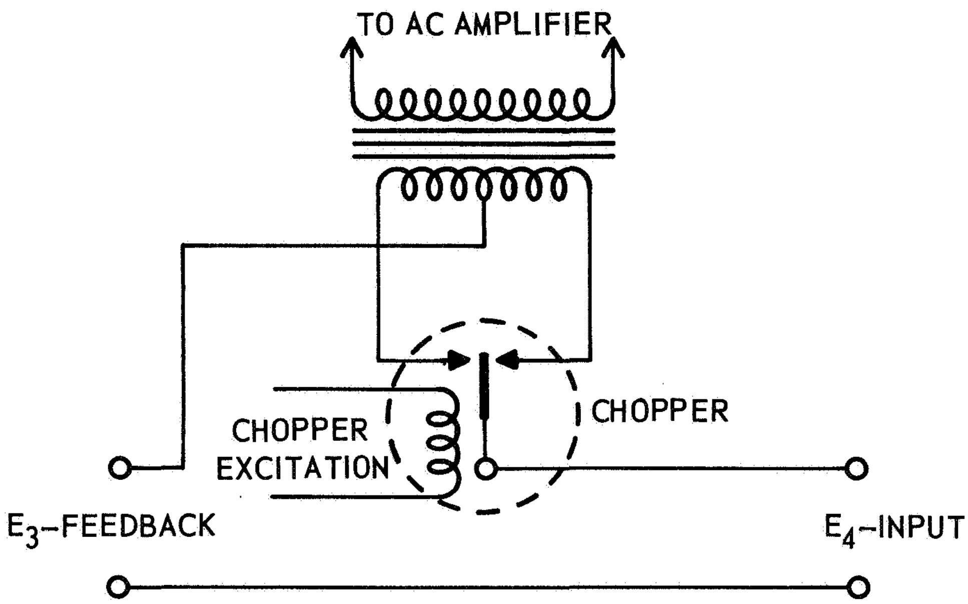
A typical chopper converter is shown in Figure 5(A), and a circuit simulating the chopper input drift voltage is shown in Figure 5(B). The effects of drift voltage E_D are shown by:

$$E_2 = (E_3 + E_D)\, G_s$$

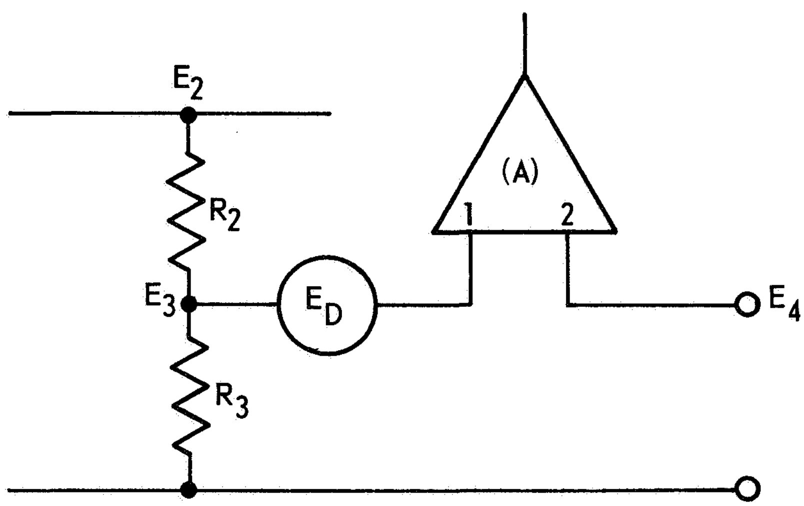
or $$E_2 = E_3 G_s + E_D G_s$$

so: $$E_{2D} = E_D G_s \qquad (14)$$

It can be seen that any drift voltage E_D will be amplified by the factor G_s, added to E_2 as an error or drift. Fortunately, the causes of E_D in the chopper input circuit are very likely to occur in both sides of the circuit, and thus the effects are very likely to cancel out. In any event, careful design and fabrication can reduce the effects to a required minimum.



A. CHOPPER DC-AC CONVERTER



B. SIMULATED DRIFT VOLTAGE INTO DC-AC CONVERTER

Figure 5., Amplifier (A) Input Drift Voltage

SECTION V. EXPERIMENTAL WORK

The only experimental work that has been done to date was the fabrication of a breadboard model to test the theory of operation. This model was designed to accept a range of input voltages from 0 to 3 millivolts with an output voltage range from 0 to 3 volts. Very good stability was achieved with this effective dc amplification ratio of 1000. Stability calculations were made using the parameters of the breadboard components and it was found that a long term stability of no greater than ± 0.1 millivolt variation in the output voltage (input at nominal) was feasible. Inasmuch as this stability satisfied the requirements existing at that time, no further experimental work was done.

SECTION VI. CONCLUSIONS AND RECOMMENDATIONS

A novel dc voltage amplifier has been conceived. The amplifier may be designed to have an excellent stability of the amplification ratio, with this ratio being primarily controlled by the ratio of two resistors. The factors which have critical effects on the gain accuracy and drift are the potentiometer resolution, the static friction of the mechanical portion of the system, and the dc voltage drift generated by the input to the dc to ac converter. Adverse effects of all of these critical factors can be overcome by careful design.

Cost comparisons have been made with comparable commercial instruments and it has been found that the subject system can cost much less than a conventional electronic dc amplifier of equivalent stability. Therefore, when amplification of multiple channels of low-level, steady-state or slowly-changing dc voltages is required, this system would be attractive costwise. It is recommended that it be considered for such uses.

NASA TM X-53803
March 26, 1969

APPROVAL

AN ELECTRO-MECHANICAL DC VOLTAGE AMPLIFIER

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

F. Wells
Test Research Section

Frank R. Batty, Chief
Applied Technology Branch

Richard M. Henritze, Chief
Analytical Operations Division

Dieter Grau, Director
Quality and Reliability Assurance Laboratory

NASA TMX-53803
March 26, 1969

DISTRIBUTION

KSC, Mr. A Zeiler
A&TS-MS-IP, Mr. Ziak
A&TS-MS-D, Mr. H. Garrett
S&E-QUAL-A, Mr. J. Hillenbrand
S&E-QUAL-AA, Mr. E. Hendricks
S&E-QUAL-AR, Mr. F. Batty
S&E-QUAL-ART, Mr. F. Wells (50 cys)
S&E-QUAL-AT, Mr. C. Clark
S&E-QUAL-F, Mr. P. Davis (3 cys)
S&E-QUAL-OCP, Mr. R. Krone (3 cys)
S&E-ME-D, Mr. O. Eisenhardt
S&E-ME-M, Mr. J. Orr
S&E-ME-MW, Mr. G. Parks
S&E-AERO-DIR, Dr. E. Geissler
S&E-ASTR-RD, Mr. J. Gould (2)
TAT
PM-RM-M
A&TS-MS-H
A&TS-MS-IL (8 cys)
A&TS-MS-T (6 cys)

Scientific and Technical Information Facility (25)
P.O. Box 33
College Park, Maryland 20740
Attn: NASA Representative (S-AK/RKT)