CHAPTER 3

DC AMPLIFIER CIRCUITRY

25. GENERAL

The DC amplifiers used in the Nike I computer perform a number of mathematical operations. These operations are: summing, weighting, multiplying, dividing, differentiating, data smoothing, and data holding. The performance of these operations is explained in detail in this chapter. The delivered output voltage from the DC amplifier is a function of the input voltage, but is always of opposite polarity. The input and feedback network used with each DC amplifier determines the mathematical function of that amplifier. In addition to performing mathematical operations, the DC amplifier is used in the computer to reverse the polarity of a voltage analog, and to isolate one stage from another. The DC amplifier is shown on page 22 of TM 9-5000-26.

26. GENERAL REQUIREMENTS

Since the DC amplifier is required to pass steady or slowly varying signals, the coupling between stages must be made direct. Low input and output impedances are required. High gain is required, making it necessary to compensate for internal disturbances such as noise and voltage fluctuations. Negative feedback is required to insure high stability and essentially constant amplification. When the input grid of the first stage of the DC amplifier is at ground potential, the output must also be at ground potential.

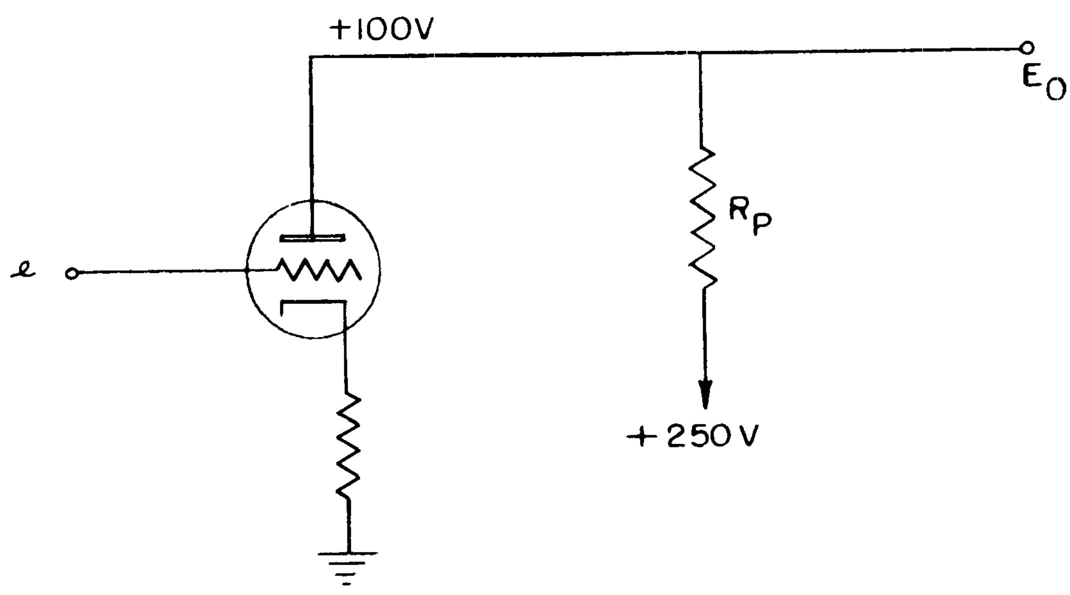

Figure 17. Single-stage DC amplifier, simplified schematic.

27. SINGLE-STAGE DC AMPLIFIER

Figure 17 illustrates a simple single-stage DC amplifier. Assume that the tube is conducting so that the plate voltage is 100 volts with no input signal, and that the gain of the tube is 10. Also assume that the stage is operating linearly. If the input were +1 volt, the tube would conduct more heavily and the plate potential would drop to 90 volts. If the input were -1 volt, the plate voltage would rise to 110 volts. By controlling the voltage on the grid, the plate current and the plate voltage may be controlled also. This simple circuit would satisfy the requirements of a DC amplifier, except for the required high gain and stability.

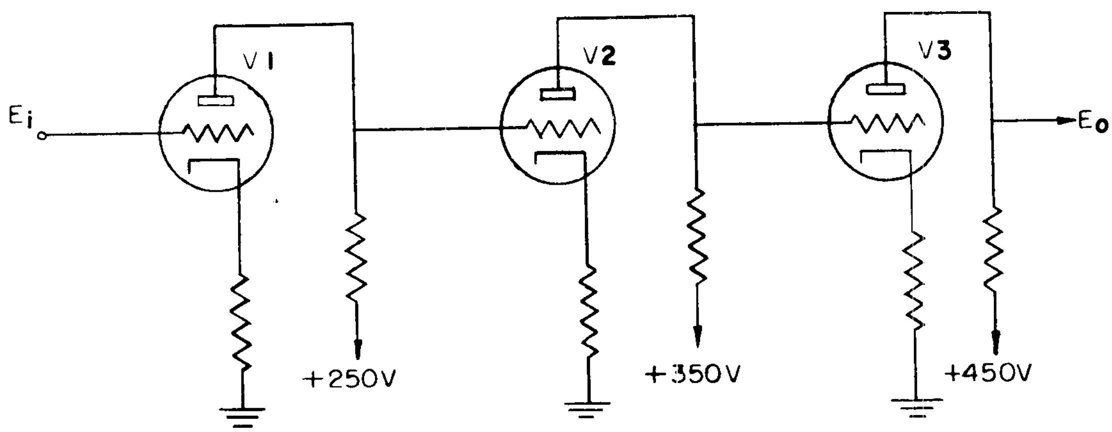

Figure 18. A basic 3-stage DC amplifier.

28. THREE-STAGE DC AMPLIFIER

A DC amplifier of greater gain is shown in figure 18. However, this circuit has the serious disadvantage of producing an output voltage of excessive magnitude when the input grid is at ground potential. If, under no-signal conditions, the voltage at the plate of the first tube is 100 volts, the grid of the second tube must also be at a 100-volt level. To obtain the correct operating point for V2, the cathode of V2 must be made approximately 100 volts positive with respect to ground. To achieve a plate-to-cathode voltage of V1, the supply voltage of V2 must be raised to approximately 350 volts. This same principle applies to the third stage, which requires a plate-supply voltage of approximately 450 volts. The output taken at the plate of V3 under no-signal condition would be around +300 volts. However, it is required that the output of the DC amplifier be zero when no input voltage is applied. This requirement may be met by the use of voltage dividers, as illustrated in figure 19, and by returning the cathode of V3 to a negative potential. By connecting a voltage divider between the plate of V1 and a negative supply, the grid potential of V2 may be held at a value near ground that will afford the desired bias for that stage. To provide a zero potential at the plate of V3 in the absence of an input signal, the cathode of V3 must be at a potential below ground. This is obtained by returning the cathode resistor of V3 to a negative voltage source. The values of resistance in the voltage divider supplying the grid of V3 must be such that the grid potential is placed well below ground. A modified DC amplifier of this type may be refined by circuit additions designed to improve stability and accuracy and to minimize drift. Improved DC amplifiers of this type are used in the Nike I computer.

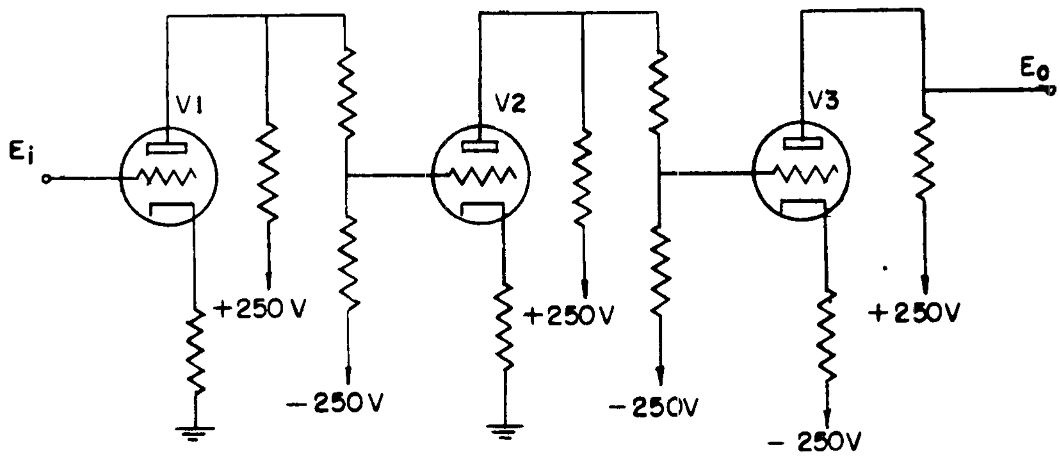

Figure 19. A modified 3-stage DC amplifier.

29. REVERSAL OF POLARITY

The output voltage of a vacuum-tube circuit is normally of opposite polarity to the input signal, except for cathode-follower circuits. Any odd number of vacuum-tube stages connected in cascade will reverse the polarity.

30. INVERSE FEEDBACK

A simple method for obtaining inverse, or negative, feedback is shown in figure 20. The amplifier is represented by a box device with a gain of K. A voltage, E_i, at the input will produce a voltage, e, at the grid. Voltage e is then amplified and appears at the output as E_o which is equal to $-K_e$. A portion of this voltage is fed back to the grid through resistor R_b. Since the feedback voltage is opposite in polarity to the input voltage, it will act to reduce the grid voltage, e. This reduction of e reduces $-K_e$, which again allows grid voltage e to increase until a point of stabilization is reached. The stabilization occurs almost instantaneously. A change in the load will cause E_o to change slightly, but inverse feedback will rapidly return E_o to its proper value. Although the use of feedback reduces amplifier gain, the advantages of stability, accurate reproduction, and low input and output impedance which it provides are required for DC amplifiers used in the Nike I computer. Later sections in this chapter include a more complete discussion on negative feedback, input networks, and DC amplifier functions.

31. ISOLATION

Some of the computer circuits tend to very in performance as the load changes, and hence must be isolated from the load. The low output impedance characteristic of a DC amplifier makes it ideal as a buffer unit. In figure 21, the voltage drop across the two resistors must equal the 100-volt supply. If R1 and R2 are equal in value, the voltage drop across each resistor is 50 volts. If R1 is reduced to 50 ohms, so that R2 is two-thirds of the load, then the drop across R2 will be two-thirds of the supply voltage, or 66.7 volts. By changing R1 to 1 ohm and R2 to 49 ohms, the voltage drop across R2 becomes 98 volts. As R2 is increased in value from 49 ohms to 99 ohms, the drop across R2 increases from 98 volts to 99 volts, a change of only 1 volt. If R1 is made small enough, a change in R2 will have practically no effect upon the voltage across R2. Consider R1 as being the output impedance of the DC amplifier, and R2 as being the load. The effective output impedance of the DC amplifiers used in the Nike I computer is approximately 1 ohm. Because of this low impedance, the output voltage of the DC amplifier does not change as a result of normal load changes. Thus, when the DC amplifier is used as a buffer unit, a change in the load circuit will not appreciably affect the source circuit.

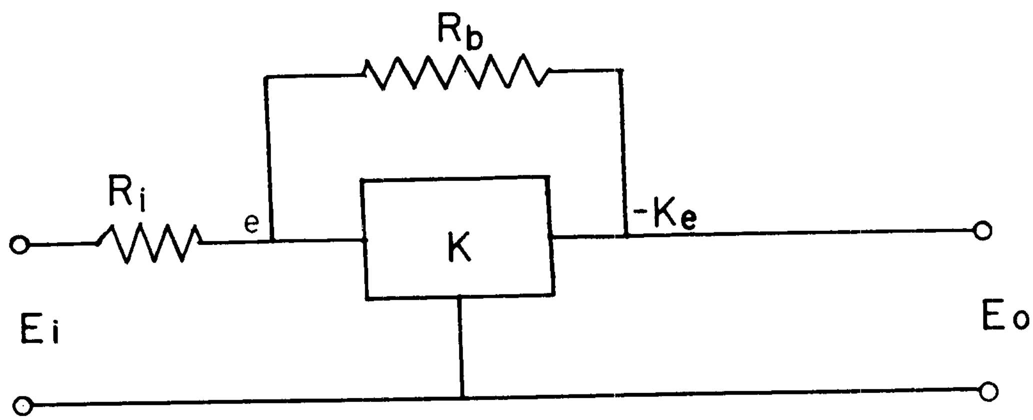

Figure 20. Inverse feedback.

32. INPUT IMPEDANCE

For an amplifier to perform algebraic operations involving several input signals, the apparent input impedance must be low. In an ordinary amplifier this impedance is extremely high. Because of inverse feedback, the effective input impedance of the Nike I DC amplifiers is low, on the order of 25 ohms. In figure 20, the voltage drop across R_i is E_i minus e. Assume that the amplifier and the feedback circuit are replaced by a resistor connected to ground, and that the value of the replacement resistor is such that E_i and e remain unchanged. Because e is very small compared to E_i, the replacement resistor must be very small compared with R_i. But the replacement resistor is the input impedance of the DC amplifier. Therefore, the apparent input impedance of the amplifier is low.

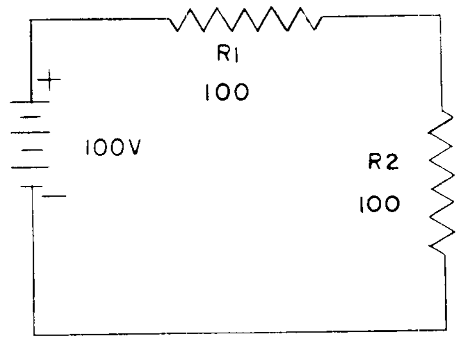

Figure 21. D-C resistance circuit.

33. DRIFT COMPENSATION

The DC amplifier must deliver an output voltage proportional to the input voltage. However, supply voltages vary and cathode emission changes. Stability and freedom from drift are extremely important in the first stage since an error here is multiplied by the gain of the succeeding stages. For example, if the gain of the second and third stages were 200 and 5 respectively, then changes in the first stage would be amplified 1,000 times in the output. Power-supply drift is corrected by careful regulation. The principal remaining source of drift is variation in operation of the vacuum tube stages, particularly changes in cathode emission. A simple method of compensation for changes in cathode emission is illustrated in figure 22. This method uses a cathode stabilizing circuit, V1B. An increase in the cathode emission of V1A would increase the plate current of V1A and would tend to increase the cathode potential. Such a change would result in increased bias for V1B, decreasing current through V1B, and thus would restore the cathode potential of the two stages to the original value. In the Nike I computer, stabilization of the first stage of the DC amplifier is accomplished with greater accuracy than the above illustration would provide. Three important drift correcting factors used are:

a. The tube used for the first stage of the DC amplifier was designed primarily for this use. It was especially designed to provide medium gain, high electrical stability, and low drift.

b. A large, unbypassed cathode resistor is used in the first stage, partially correcting for cathode variations by cathode degeneration. Since the grid of the first stage must operate near ground potential,in order to use a large cathode resistor, it is necessary to use -250 volts for the cathode voltage supply.

c. A third method of drift correction is the use of an automatic zero-setting circuit. This circuit periodically samples the potential at the input grid of the DC amplifier. If the amplifier has drifted, a small voltage will have developed at the input grid through the feedback resistor. The automatic zero-setting control amplifies this small voltage and applies it, to correct the drift, to the cathode of the first stage of the DC amplifier, through a regulator stage that uses a cathode resistor in common with the DC amplifier first stage. A complete discussion on automatic zero-setting controls is given in chapter 4.

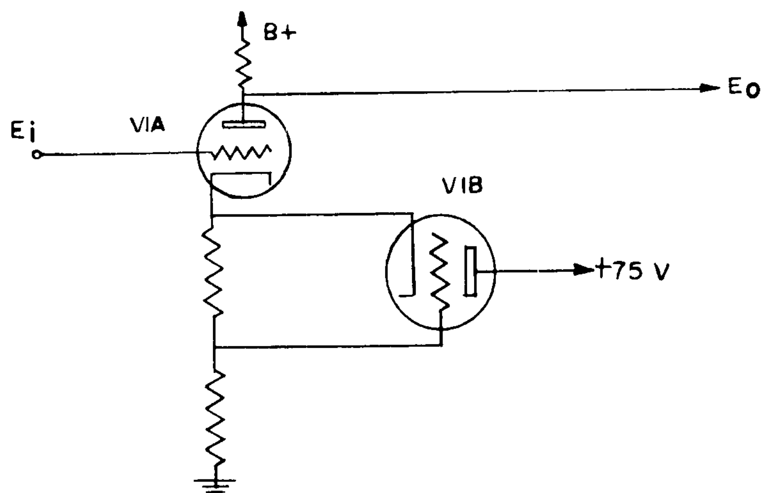

Figure 22. Cathode stabilization circuit.

34. BLOCK DIAGRAM DISCUSSION

The DC amplifier consists of three stages connected in cascade. A negative feedback circuit is connected from the plate of the output stage to the grid of the first stage. The first stage uses the A-section of a twin triode. The B-section of the twin triode is used as the regulator tube that applies the drift-correcting voltage from the automatic zero-setting control. The second stage is a high-gain pentode, and the third stage is one section of a twin triode that is capable of current amplification. Connections between stages are metallic, to accommodate passage of d-c voltages. The DC amplifiers are built on removable chassis. Each chassis mounts two DC amplifiers. The chassis are mounted in 4 rows on each of the 2 front equipment frames inside the amplifier cabinet. The input and feedback networks for the DC amplifiers are mounted on the two front equipment frames and except for the input networks used with differentiating amplifiers, are directly below the chassis of the DC amplifier with which they are associated. The plate-load resistors for the last stages of the DC amplifiers are mounted on a special panel at the bottom of the two front equipment frames. The DC amplifier chassis are identical and interchangeable. The net gain of the DC amplifier is rated between 30,000 and 40,000. The gain is greatly increased by the use of automatic zero-setting controls.

35. DETAILED CIRCUITRY

The schematic on page 22 of TM 9-5000-26 represents one of 38 identical DC amplifier chassis used in the Nike I computer. This unit has 2 identical channels designed to operate as 2 independent DC amplifiers. To make the unit universal in application, the input circuit for each channel is mounted separately in a network that usually contains one or more input resistors and a feedback circuit. The input networks are connected to the DC amplifiers at P2 and P3. The connecting leads between the input networks and the input grid of each DC amplifier are shielded to prevent the small d-c error signals traveling over these leads from being affected by stray magnetic fields. The feedback networks and plate-load resistors for the last stages of the two DC amplifiers connect through pins 5 and 7 of P1. The plate-load resistors are mounted separately from the DC amplifiers on the plate feed resistor panel. This separate mounting facilitates maintenance and testing. Each channel uses one twin triode (type 5755), one pentode (type 6AU5), and one section of a twin triode (type 5687), for the first, second, and third stages respectively.

36. POWER REQUIREMENTS

To establish the proper operating level for each of the three stages, the following voltage supplies are used: a plate supply of +250 volts is used for the first and second stages; a plate supply of +320 volts is used for the third stage; the cathodes of the first stage are returned to the -250-volt supply; the cathode of the second stage is returned to ground; the cathode of the third stage is returned to the -200-volt supply. To establish proper grid biasing for the second and third stages, the grid resistor of the second stage is returned to the -250-volt supply and the grid resistor of the third stage is returned to the -320-volt supply. The screen grid of the second stage, the 6AU5 pentode, is biased to +75 volts from the +75-volt supply. The filaments of the tubes of the first and second stages are heated by a 6.3-volt, a-c supply. The filament of the third stage is also heated by 6.3 volts a-c. However, since the cathode of the third stage is connected to -200 volts, and since a cathode resistor is not used, one side of the filament is connected to the cathode to prevent an excessive d-c potential from existing between cathode and filament of the stage. This eliminates the possibility of arcing between cathode and filament.

37. PHASE SHIFT AND HIGH-FREQUENCY COMPENSATION

The DC amplifier must be capable of handling fluctuating d-c signals. The a-c components present in these signals are retarded in phase between the input and the output of the amplifier. The phase lag is caused primarily by grid-to-ground, plate-to-ground and interelectrode capacitance. At some frequency, this phase lag is enough to turn the normal negative feedback into a positive feedback. Positive feedback, in turn, causes oscillation and increases the gain of the circuit. As a result, the amplifier would be unstable. Capacitors connected across the coupling resistors between stages advance the phase of the a-c components to partially equalize the phase lag. Also, the high-frequency, a-c components are attenuated through series R-C combinations connected between plate and ground of the first stage, and between grid and cathode of the third stage. High frequencies at the plate of the third stage are also shunted to ground through a capacitor. These high-frequency attenuating capacitors lower the gain of the amplifier below unity at the potential oscillating frequency, so that in spite of the regenerative feedback at higher frequencies, oscillations are not sustained and the amplifier remains stable. Capacitors C2, C4, C12, and C14 are lead capacitors shunting their respective coupling resistors. These capacitors do not solve the phase problem entirely, but they do increase the frequency at which the normal negative feedback is shifted 180° in phase to become positive feedback. Capacitors C5A and C5B, shunting the plates of the output stages of the amplifiers to ground, are the attenuating capacitors which reduce the gain of the amplifiers to less than unity at the frequency at which a 180° phase shift occurs. The R-C combinations, C1-R2, C11-R22, C3-R12, and C13-R32 perform a similar attenuating function. The combined action of the lead-producing capacitors and the attenuating networks stabilizes the DC amplifiers. The attenuating networks reduce the gain of the amplifiers to less than unity at frequencies above 20 kc, and the lead-producing networks insure that a complete 180° phase shift will not occur for frequencies below 80 kc. Thus, a wide safety margin for stability is provided. The B-sections of tubes V1 and V3 are the regulating stages through which the automatic zero-setting control drift-correction voltages are applied to the first stages of the DC amplifiers. Under ideal operating conditions, when there is no input signal, the plate of the third stage would be at ground potential. The automatic zero-setting control correction voltage would be zero and the grid of the regulator stage would be at ground potential. However, when drift causes the plate of the output stage to vary from zero potential under no-signal condition, the feedback current will cause a small d-c potential to develop at the grid of the first stage. The automatic zero-setting control samples this voltage, amplifies it, and applies a correcting voltage to the grid of the regulator stage, of the proper polarity to correct the drift and to bring the plate of the output stage back to ground potential.

38. FEEDBACK

The term feedback signifies that some of the output signal is returned to the input of the amplifier stage. If the returned signal has the same polarity as the input, it aids the applied signal, and this feedback is termed positive or regenerative. If the returned signal is of opposite polarity, it subtracts from the applied signal and is called negative or degenerative. Since sign reversal occurs in a computer DC amplifier, the output will be opposite from the input in polarity. The feedback is a portion of the output voltage and is consequently of opposite polarity to the input voltage. Therefore this feedback is negative or degenerative.

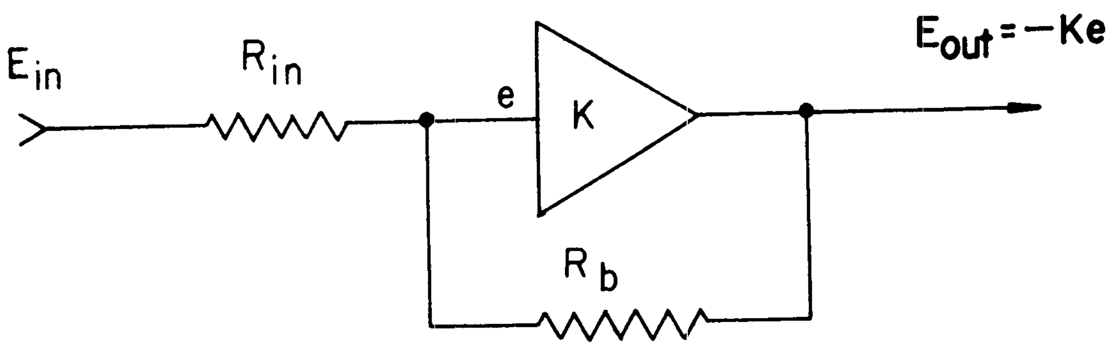

Figure 23. Simple DC amplifier with negative feedback.

39. EFFECT OF NEGATIVE FEEDBACK (fig 23)

A voltage, E_{in}, applied to the input resistor, R_{in}, produces a voltage, e, at the grid. If K is the gain of the amplifier, E_{out} will be equal to -Ke. A portion of this voltage will be returned to the input through R_b, and, since it is opposite in sign to E_{in}, it will tend to reduce e. This reduction of e in turn will reduce -Ke, since K must remain constant. Since part of the reduction will be in the feedback, e will tend to increase again. This oscillatory movement will continue until stabilization occurs. Actually, stabilization will occur almost instantaneously. Any disturbances originating within the amplifier, such as noise voltages or power supply fluctuations, will change the value of K somewhat. An increase of K will increase the value of E_{out} and, in turn, the feedback. The increase feedback will decrease e and return

E_{out} to its old value. Similarly, a decrease of K causes E_{out} and the feedback to decrease. This causes e to increase which will bring E_{out} back to the proper value. Thereby, the ratio between the input and output voltages is kept practically constant, although K may vary somewhat. Thus, the computer DC amplifier has great inherent stability because of the negative feedback used.

40. EFFECT OF INCREASED GAIN

One of the greatest advantages of negative feedback is that it causes almost perfect reproduction of the input to occur in the output if enough amplification is available. In this amplifier (fig 24), the gain is 100, and the desired output is -100 volts. The voltage at the input grid, e, obviously must be 1 volt if it is to be amplified to 100 volts by a gain of 100. The feedback will be -100 volts and will be combined with the input voltage. With this feedback, the

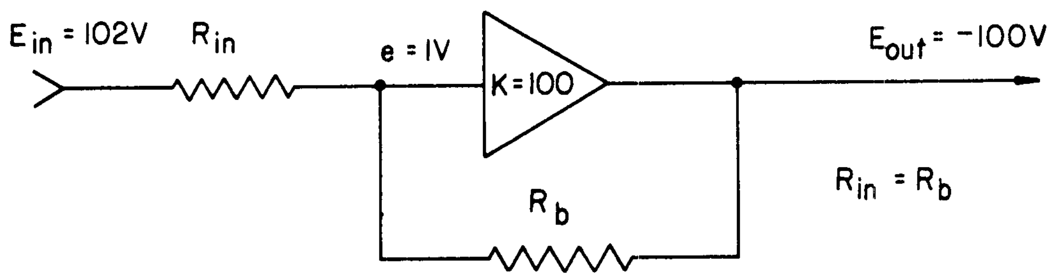

Figure 24. Simple DC amplifier with gain of 100.

input voltage must be 102 volts if e is to equal 1 volt. This may not be immediately apparent to the reader. Consider the equivalent circuit in figure 25. Resistor R_{in} is equal to R_b. In this case, the same current flows through R_b and R_{in}. Therefore, the same voltage is dropped across R_b as across R_{in}.

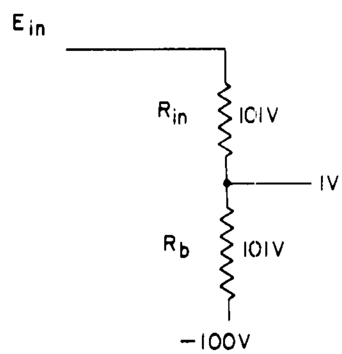

Figure 25. Equivalent circuit for figure 24.

The difference in potential between 1 volt and -100 volts is 101 volts. Therefore, the IR drop across R_b and R_{in} must be 101 volts. To have a potential difference of 101 volts between E_{in} and the input grid, E_{in} must be 101 + 1 or 102 volts. An amplifier designed to have a gain of 10,000 is shown in figure 26. Again it is desired to have E_{out} equal to -100 volts. To produce this output, e must be equal to 0.01 volt. The feedback voltage is -100 volts

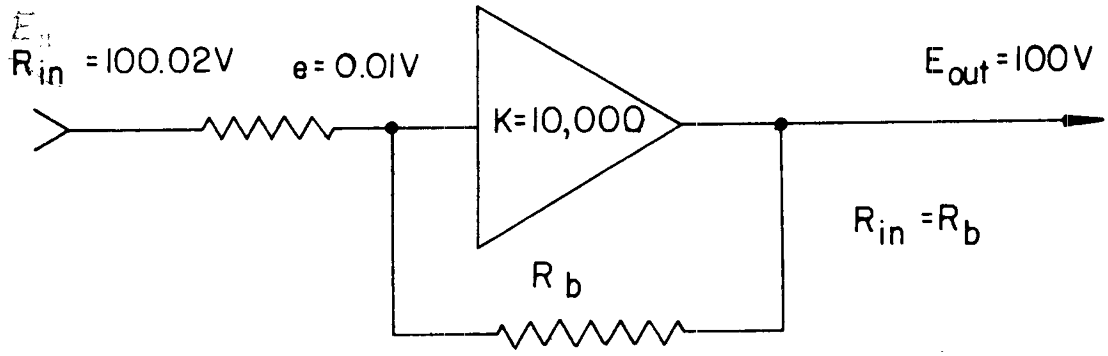

Figure 26. Simple DC amplifier with gain of 10,000.

and the voltage dropped across R_b and R_{in} is 100.01 volts. Thus E_{in} must be equal to 100.02 volts. In figure 27, the amplifier shown is similar to those found in the Nike I computer. Its gain is 20,000 and E_{out} is again -100 volts. With K equal to 20,000, e must be 0.005 volt. The IR drops across R_b and R_{in} are 100.005 volts, causing E_{in} to be equal to 100.01 volts. It is evident that the input has been almost exactly reproduced (accurate to about 10 parts in 100,000) at the output. The foregoing discussion

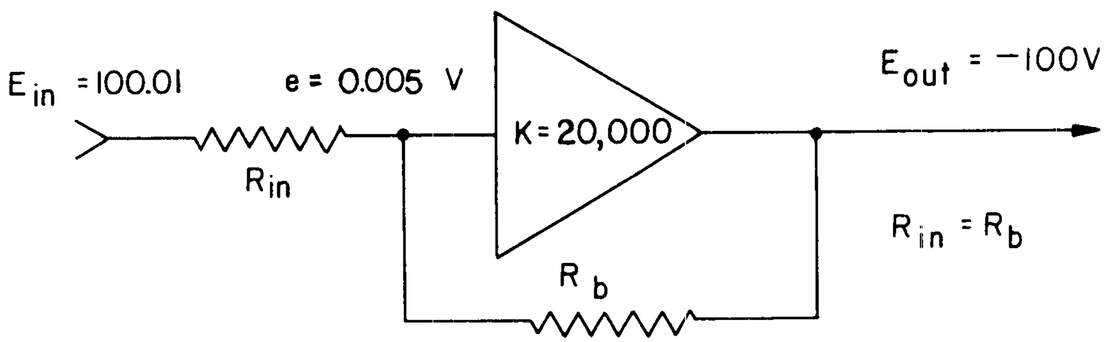

Figure 27. Simple DC amplifier with gain of 20,000.

was used to prove to the reader that the accuracy of reproduction of a DC amplifier with negative feedback is increased as the gain is increased. With the high gain of the amplifiers used in the Nike I computer, a high degree of accuracy is possible.

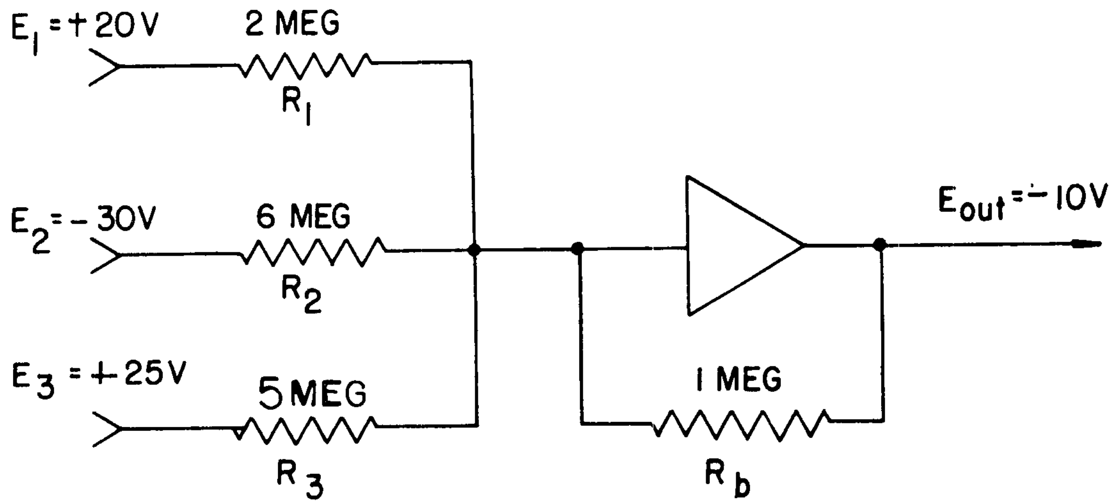

Figure 28. Summing and weighting with a DC amplifier.

41. DC AMPLIFIER SUMMING AND WEIGHTING

The DC amplifier in figure 28 has three inputs which are applied through the three resistors, R1, R2, and R3. To find the output voltage, the following formula is used:

$$-E_{out} = E1\frac{Rb}{R1} + E2\frac{Rb}{R2} + E3\frac{Rb}{R3} + \ldots E_{in}\frac{Rb}{R_{in}} \qquad (4)$$

Substituting the values from figure 28 in the formula,

$$-E_{out} = (20 \times 1/2) + (-30 \times 1/6) + 25 \times 1/5),$$

or $$-E_{out} = 10 = 5 + 5 = 10 \text{ volts},$$

or $$E_{out} = -10 \text{ volts}.$$

In this problem, three voltages were added at the input to the DC amplifier. Two of the voltages were positive and the third was negative. In addition, the voltages were weighted on entry into the amplifier. The ratio between input and feedback resistors may be demonstrated by considering the input and feedback resistors as a voltage divider with the input and feedback voltages. Figure 29 shows the input and feedback resistors arranged in the form of a voltage divider. The feedback voltage may be called E_{out}, since it is a portion of the output voltage that constitutes the feedback. For this problem

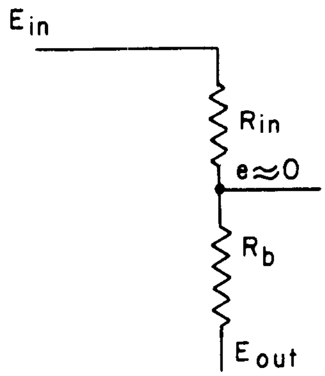

Figure 29. Ratio between input and output voltages.

consider the voltage at the amplifier input grid (the junction of R_{in} and R_b) as zero. If a voltage E_{in}, is applied to R_{in}, and R_{in} has some finite resistance, the problem is to determine how much negative voltage applied to R_b will cause zero voltage at the junction of R_{in} and R_b. Since the input grid draws almost no current, a single current flows through R_b and R_{in}. The voltage drops across R_{in} and R_b will depend upon their resistance values. A simple proportion is thus evident:

$$\frac{-E_{out}}{E_{in}} = \frac{R_b}{R_{in}} \tag{5}$$

Solving for E_{out},

$$+E_{out} = -E_{in}\frac{R_b}{R_{in}} . \tag{6}$$

This formula may be applied to single inputs or to multiple inputs as demonstrated in figure 28.

42. DIVISION

Consider the circuit shown in figure 30. The expression for the output voltage of an amplifier having such a voltage divider in the feedback circuit is as follows:

$$-E_{out} = E_{in} \times \frac{R_b}{R_{in}} \times \frac{R1 + R2}{R2} . \tag{7}$$

In this situation, with the circuit elements as indicated on figure 30, E_{out} may be computed. Substituting the values in the formula above:

$$-E_{out} = 25 + \frac{2}{1} \times \frac{25 + 50}{50} ,$$

or

$$E_{out} = -25 \times 2 \times \frac{75}{50} = -75 \text{ volts.}$$

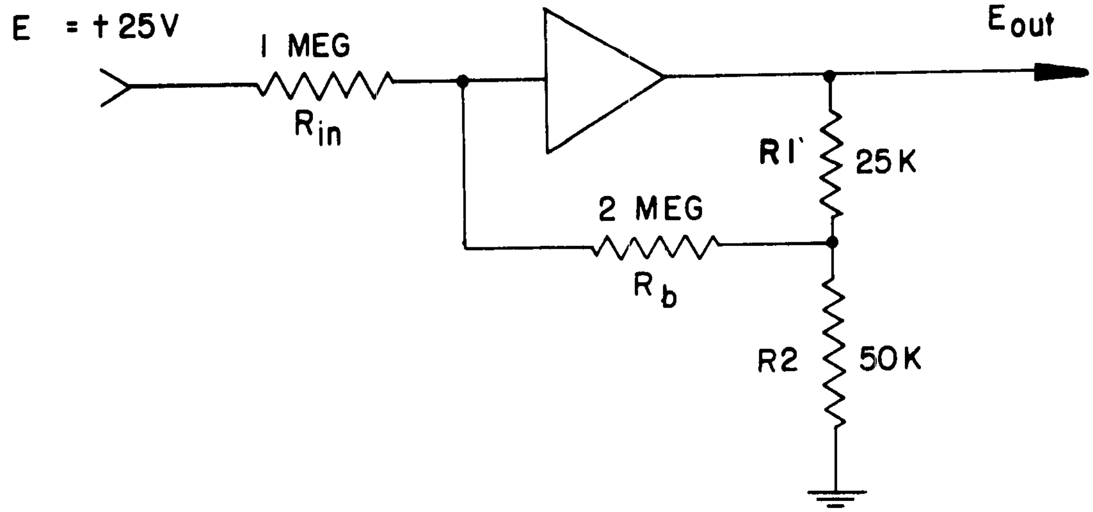

Figure 30. Division by a constant less than one.

$$+E_{out} = -20 \times \frac{1}{1} \times \frac{25}{50} = -10 \text{ volts.}$$

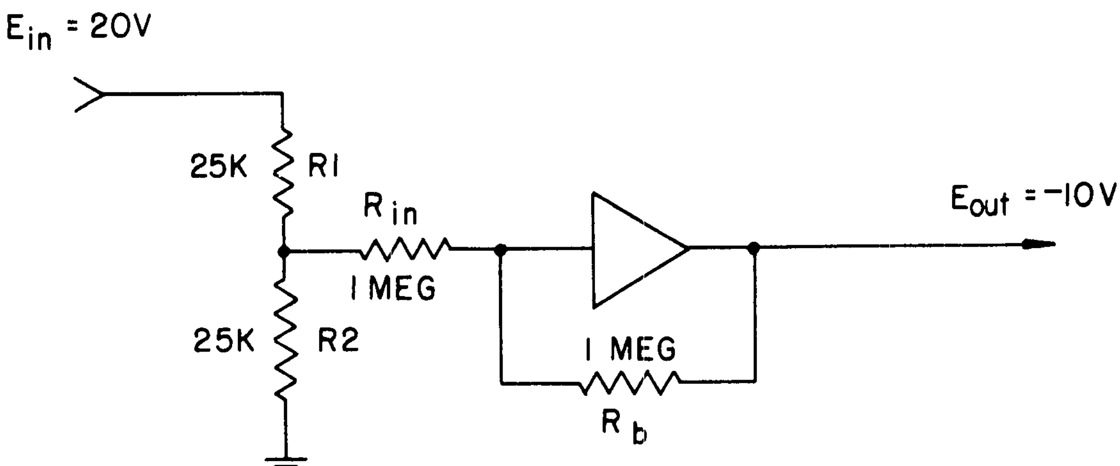

Figure 31. Multiplication by a constant less than one.

It is apparent that division has been by a constant less than 1, in this case 1/3. The student will find such voltage dividers in several feedback networks used with computer DC amplifiers. If the resistors in the feedback network are replaced by a potentiometer with the brush arm connected to the feedback resistor a similar situation results. In this case the input will be divided by a function of the brush movement, such as time or the sine or cosine of an angle.

43. MULTIPLICATION

Using the circuit shown in figure 31, an input may be multiplied by a constant less than one. In this case, the output will be represented by the following formula:

$$-E_{out} = E_{in} \times \frac{R_b}{R_{in}} \times \frac{R2}{R1 + R2} \qquad (8)$$

Substituting the values shown,

$$+E_{out} = -20 \times \frac{1}{1} \times \frac{25}{50} = -10 \text{ volts}.$$

It is evident that the input has been multiplied by a constant less than one, in this case 1/2. Again, R1 and R2 may be replaced by a potentiometer which multiplies by some varying function, such as time or the sine or cosine of an angle.

44. DIFFERENTIATION

It is of the utmost important in the Nike I computer to develop voltages which represent velocities of target and missile. The student should have seen in chapter 2 that the present locations of target and missile may be determined in rectangular coordinates. The student should understand how voltages representing the coordinate rates are derived.

45. OBTAINING $\dot{X}_T$ FROM X_T

Figure 32 shows a capacitor as the input to a conventional DC amplifier. Consider an input voltage, E_{in}, having rate of change of $\dot{E}_{in}$. The voltage at the input grid of the DC amplifier is called e and is given by the following formula:

$$E_{out} = \dot{E}_{in} R_b C = -Ke, \qquad (9)$$

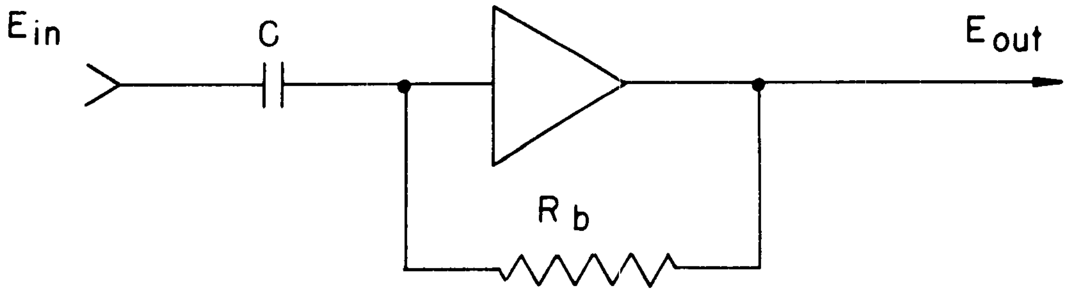

Figure 32. Differentiation in a DC amplifier.

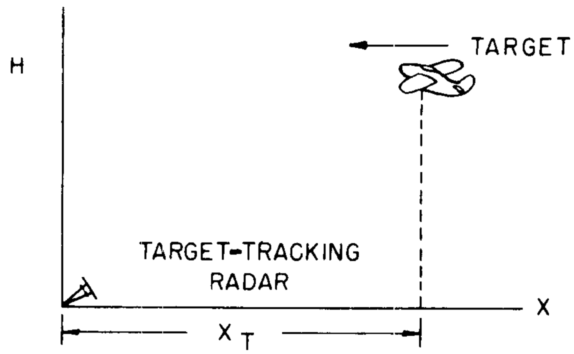

Figure 33. A target aircraft approaching from the east.

where R_b is the amplifier feedback resistor and C is the input capacitor. The terms are important in this formula: $\dot{E}_{in}$ in volts per second, R_bC in seconds, and E_{out} in volts. For a steady d-c voltage, $\dot{E}_{in}$ will be zero and it follows that E_{out} must be zero. Consider the situation given in figure 33. A target is approaching a Nike battery from the east at a certain velocity. It is possible to determine X_T from data available at the target tracking radar. If the target has velocity it must be changing at a certain rate. The problem is to develop a voltage which represents that rate. In the computer, X_T, a positive quantity, may be represented by a negative voltage. This negative voltage is going positive toward zero. It is applied to a differentiating network similar to that shown in figure 32. In the formula, $E_{out} = R_bC\ \dot{E}_{in}$, $\dot{E}_{in}$ will be positive for the conditions imposed by figure 33. Therefore, E_{out} will be a negative voltage. This is proper because the target is flying in a westerly (negative) direction. If the target were flying in the opposite direction, $\dot{E}_{in}$ would be negative and E_{out} would be positive. Again this is proper because the target would be flying in an easterly (positive) direction.

46. DATA SMOOTHING

Incorporated with the computer differentiating circuits are data-smoothing networks. The voltages which represent velocities as developed by differentiating circuits contain a considerable number of transients which must be minimized to obtain the desired system accuracy. These transients, described as electrical noise, result from random effects such as tracking antenna hunting and granularity of the wirewound potentiometer cards. The data-smoothing networks are resistance-capacitance networks which delay the transmission of variations in the rate voltages and spread their effect over a period of time, thus smoothing out irregularities. The Nike I computer uses two types of data-smoothing networks: 2-second and 4-second. The 4-second data smoothing nets are available to the computer during the prelaunch configuration for the target differentiator only. The 2-second data smoothing nets are available to the computer during the steering configuration for both target and missile differentiators.

47. FOUR-SECOND DATA SMOOTHING

In a simple R-C filter, the capacitor may be said to store the various rises and falls of the input voltage and provide a more smoothly varying d-c voltage as an average output. The larger the capacitor used, the smoother the output. The word average indicates that the voltage was considered over a period of time. In an R-C filter, the charging time constant increases if one or the other element is increased in value. Generally speaking, the larger data-smoothing time allowed, the smoother the output voltage will be. A more complex circuit is used than the simple R-C network referred to previously. The more complex network provides maximum smoothing in a minimum time delay. The 4-second data smoothing network has a response that depends upon input data during a 4-second period. It places most importance (weighting) on data only about 1.6 seconds late. A graph of this is illustrated in figure 34 and is called the weighting function. The curve in figure 34 shows the relative importance the circuit places on data with respect to the length of time during which that data are present in the 4-second period. Although the peak of this curve occurs at -1 second, the circuit delay is measured in terms of the line which divides the curve into two halves of equal area. This line occurs at -1.6 seconds. From the curve in figure 34, it is seen that there is no response at the time that data appears, but, if these data remain for a significant period of time, the response increases to a maximum. After this time, the data are too old to be very important and the response drops until, at 4 seconds old, it is completely discarded.

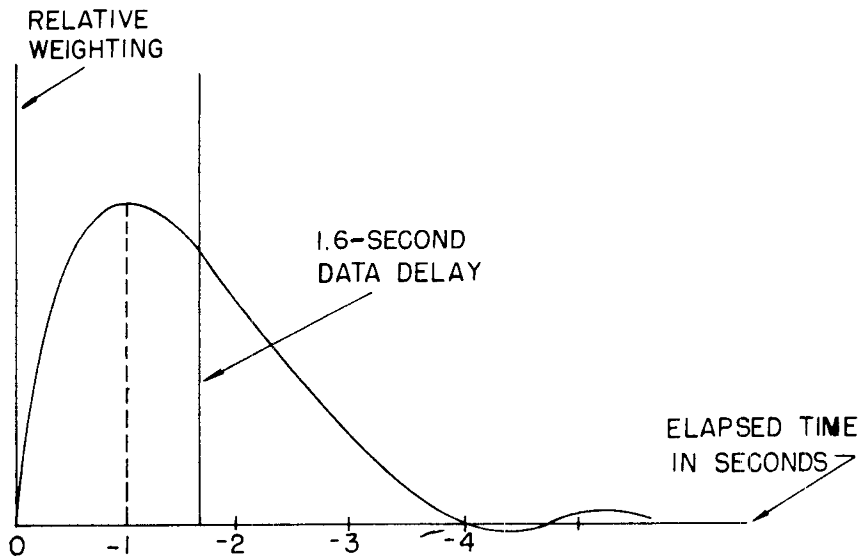

Figure 34. Weighting function for a 4-second data-smoothing network.

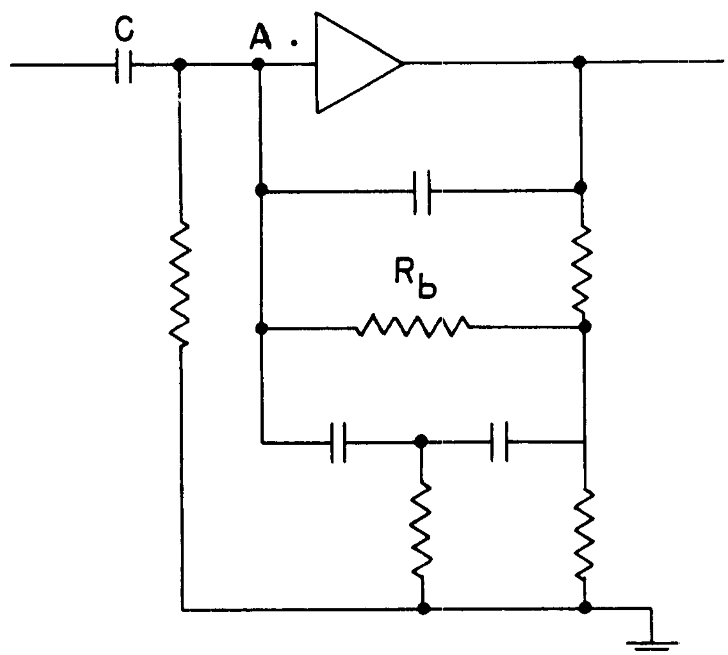

Figure 35. Differentiating amplifier, simplified schematic.

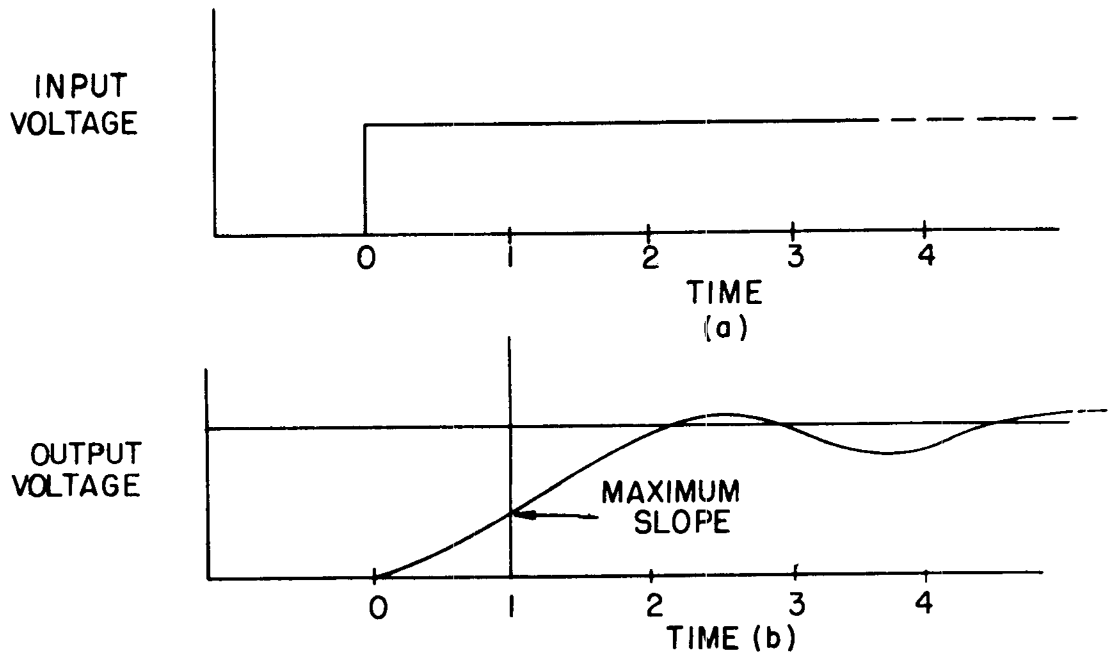

Figure 36. Input and output voltages of a data-smoothing network.

a. In actual practice, the data smoothing network is a complex R-C circuit, placed in the amplifier feedback path so as to parallel the feedback resistor. The amplifier output depends upon the characteristics of this integrating circuit. A simplified schematic of a differentiating amplifier with its input and feedback network is shown in figure 35. The input capacitor is labeled C and the feedback resistor is labeled R_b. Note the complex R-C network shunting R_b.

b. The behavior of the data smoothing network can be tested by suddenly applying a d-c voltage at point A (fig 35) and observing the output. This is illustrated in figure 36. The input is a step function as indicated in figure 36a. The output (fig 36b) at time zero is zero. One second later, the output is responding most rapidly (fig 34). Finally, after 4 seconds have passed, the output is no longer changing. The output will remain at full value as long as the input remains constant, since a DC amplifier is being used. Remember that the step function of voltage is not applied directly to the differentiator capacitor, but to the input grid of the DC amplifier.

48. DIRECT COUPLING

A DC amplifier is an electronic device that produces an output voltage proportional to the input voltage when the input voltage is a d-c signal. The symbol

DC means direct coupled. That is, the coupling between the plate of one tube and the grid of the next tube must not involve either a capacitor or a transformer, otherwise a change from one steady voltage condition to another steady voltage condition would not be transmitted. The term d-c indicates direct current, which is a steady state or nonalternating condition.

49. FUNCTION OF THE DC AMPLIFIER

There are 76 DC amplifiers in the Nike I computer. All are identical and interchangeable, except for their input and feedback networks. They may be used to perform any or all of the following different functions:

a. Reverse the polarity of the input voltage.

b. Isolate one circuit element from another.

c. Produce a d-c voltage proportional to the algebraic sum of two or more d-c voltages, either with or without weighting one or more of the input voltages.

d. Multiply or divide any of several input voltages by any desired fixed factor.

50. SPECIFICATIONS OF THE DC AMPLIFIER

a. Number of stages: 3.

b. Net gain: 20,000.

c. Apparent input impedance: about 25 ohms.

d. Effective output impedance: about 1 ohm.

e. Tubes used: first stage - 5755,
second stage - 6AU6,
third stage - One-half of a 5687.

f. As used in the computer, the DC amplifier is essentially a 3-stage, resistance-coupled, vacuum tube amplifier, using negative feedback.