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Operating Handbook

Donner Model 3000

Analog Computer

ADVANCED
INSTRUMENTATION

DONNER SCIENTIFIC COMPANY

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Operating Handbook

Donner Model 3000

Analog Computer

Serial Number ____________

DONNER MODEL 3000
ANALOG COMPUTER

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DONNER SCIENTIFIC COMPANY

WARRANTY

Donner instruments are warranted during a period of one year from date of shipment to original purchaser to be free from defects in material and workmanship. This warranty does not apply to vacuum tubes, except as they are warranted by tube manufacturers. The liability of Seller under this warranty is limited to replacing or repairing any instrument or component thereof which is returned by Buyer at his expense during such period and which has not been subjected to misuse, neglect, improper installations, repair, alteration, or accident. Seller shall have the right of final determination as to the existence and cause of a defect. In no event shall Seller be liable for collateral or consequential damages. This warranty is in lieu of any other warranty, express, implied or statutory, and no agreement extending or modifyingit will be binding upon Seller unless in writing and signed by a duly authorized officer.

RECEIVING INSPECTION

Every Donner instrument is carefully inspected and is in perfect working order at the time of shipment. Each instrument should be checked as soon as received. If the unit is damaged in any way or fails to operate, a claim should immediately be filed with the transportation company.

REPAIRS

Whenever a Donner instrument requires service, the nearest Donner representative should be contacted; all representatives will provide immediate service or arrange factory returns when necessary.

Please specify both model and serial number in all correspondence concerning Donner instruments. Address all inquiries on operation or applications of Donner instruments to your nearest sales representative or Sales Manager, Donner Scientific Company, 888 Galindo Street, Concord, California.

GENERAL DESCRIPTION

The Donner Model 3000 is a compact electronic analog computer for the precise, quantitative solution of linear (and certain classes of non-linear) differential equations and transfer functions. The instrument contains ten DC operational amplifiers, any one of which may serve the functions of addition, subtraction, multiplication or division by a constant, sign changing, or integration. Problems expressed as differential equations are entered in terms of electrical components on a detachable problem board. Stability and accuracy of the computer are satisfactory for problem solution times up to 100 seconds or more, to permit accurate recording with conventional pen recorders. However, amplifier bandwidth and relay operation speed are adequate for repetitive-solution operation up to 10 cycles per second with oscilloscope readout.

The Model 3000 is packaged in a two-module cabinet, complete with all necessary power supplies. It can readily be accommodated on the desk or bench of the user. Where more than ten operational amplifiers are required, two or more Model 3000 Computers may easily be interconnected to serve as a single larger computer. The Model 3000 Computer requires only one or more detachable problem boards, plus computing components, to be fully operational.

SPECIFICATIONS

Amplifiers

The ten operational amplifiers employ a stable, high-gain DC circuit, with a pentode driving a cathode-follower output. A VR tube coupling element allows both input and output signals to be centered precisely about zero voltage. Each amplifier has the following characteristics:

Gain: Basic gain of 1000, increased by positive feedback to more than 30,000 over most of the full output range. Average gain over full range greater than 10,000 (open loop characteristic).

Bandwidth: When used as a negative feedback amplifier with a gain of 10, amplifier phase shift reaches 1 degree at a signal frequency of approximately 10,000 cps.

Input Impedance: Input impedance of each amplifier is that of an open-grid pentode amplifier. Computing resistances may have any value from 20×10^3 to 20×10^6 ohms.

Grid Current: Total grid current in the input tube of any operational amplifier is on the order of 10^{-10} amperes, and regularly lies below 1 millimicroampere.

Output Impedance: In normal use as a negative feedback amplifier, the very high loop gain reduces output impedance of the unit to less than one ohm.

Output Capabilities: Output voltage may have any value between + 100 and - 100 volts with load currents up to 5 milliamperes of either polarity (minimum load resistance 20,000 ohms). Peak power output of any amplifier is approximately 0.5 watt.

Crosstalk: At 1000 cps, maximum intercoupling to the amplifier next following on problem board is approximately 40 db down from full output, with unity gain amplifiers and impedance level at 1 megohm. Maximum intercoupling to all other amplifiers is approximately 60 db down from full output. Corresponding intercoupling figures at signal frequency of 60 cps are 60db and 80 db.

Hum Level: AC hum level on the output of any operational amplifier is normally about 1 millivolt, more than 90 db down from full output.

Drift: Short-term random drift is less than ± 2 mv under normal operating conditions. Long-period drift is less than 4 mv/hr after two-hour warmup.

Overload: Amplifiers operate without overload up to + 100 and - 100 volts output at 5 milliamperes. As load current is reduced the output voltage range is increased, but should not be relied upon beyond approximately ± 110 volts. Approaching overload or actual overload with attendant nonlinear operation of any amplifier is indicated by the lighting of the corresponding neon lamp on the amplifier panel.

Adjustments: Potentiometers with slotted shafts, provided for Gain Adjustment and for Coarse DC Balance adjustment of the invididual amplifiers, are conveniently located on the amplifier chassis just inside the computer cabinet. The Fine DC Balance adjustments are controlled by knobs which are located on the front panel.

Meter

The amplifier chassis is equipped with a 4 1/2" zero-center meter which is used for coarse and fine balance adjustment of each operational amplifier. The meter may also be used as a visual monitor on the output of any amplifier during computer operation, three ranges being provided.

Initial-condition Voltage Supplies

Five isolated power supplies are provided to set initial-condition voltages or other input functions. Each power supply has a voltage output which may be connected for either polarity, and which is variable by potentiometer control from zero to 100 volts at up to 5 milliamperes load. Output terminals of the individual power supplies are available from the row of jacks on the power supply panel, just above the problem board. The initial-condition power supplies have a long-time stability better than 0.5% full-scale value.

Initial-condition Relays

Five low-level and five high-level double-throw relay poles, with terminals available on the problem board, are operated by the COMPUTE-RESET switch on the power supply panel. They may be connected to set in or remove initial conditions, or to apply a system disturbance (step function) at the start of a problem solution.

Diode Limiters

The plate and cathode connections of two thermionic diodes are available on the Model 3034 (and Model 3033) Problem Board. The diodes (a Type 6AL5 tube), have their plate and cathode leads brought through the connector which accepts the problem board.

Hold Relays

Five single-throw relay poles are actuated by the HOLD-OPERATE switch on the power supply panel to arrest problem solution for readout of parameters. Switching back to OPERATE continues the solution.

Main Power Supplies

Both positive and negative high voltage supplies are regulated to approximately 0.25%. Outputs are + 370 volts at 180 milliamperes maximum and - 300 volts at 130 milliamperes. Heaters of the input pentodes in the operational amplifiers are VR-transformer regulated for stability of DC amplifier balance.

Dimensions

Computer cabinet 21 1/2 wide x 19 1/2 high x 15 inches deep.
Problem board 21 wide x 2 high x 14 inches deep.

Weight

Approximately 102 pounds (net); 110 pounds (shipping).

Input Power Requirements

105-125 volts, 60 cps, 350 watts; 210-250 volts, 50 cps, special order.

THEORY OF OPERATION

General

The Donner Model 3000 Analog Computer* is a DC electronic differential analyzer which solves physical or mathematical problems by fundamental analogy between two equations or sets of equations. One set of equations expresses the problem which the computer is asked to solve. The second set is either explicitly or implicitly set up by the computer operator in order to form a consistent quantitative analogy between the two sets of equations.

In common with other modern analog computers, the Model 3000 yields the time-dependent solution of differential equations automatically through the use of operational amplifiers. These versatile computing units serve any of the fundamental functions of integration, multiplication or division by a constant, addition, subtraction, and sign changing, as required to reduce the differential equations to be solved to a closed representation in analog form. Direct analogies between single electrical components and components in the physical system are not necessary. Instead, straightforward rules of procedure permit progressive setup of the differential equations to be solved, through the steps of repeated integration and summation of terms necessary to find the variables of final interest.

Operational Amplifiers

The ten operational amplifiers in the Model 3000 Computer are all identical and are described by the simple circuit of Figure 1, Page 25. Each amplifier meets the prime requirements for reliable and accurate performance in an electronic analog computer intended for both repetitive and extended time solutions:

1. Very high forward gain, from DC up to tens of kilocycles.
2. Very low phase shift, from DC to several kilocycles.
3. Balanced operation, so that zero input corresponds to zero output, and positive or negative input signals result in proportionate output signals of opposite signs.
4. Excellent zero stability as a DC amplifier.
5. Very low grid current and very high input impedance.

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*A great many design aspects of the Model 3000 Computer are directly related to characteristics of simplified analog computers originated in the Systems Development Section, Aviation Ordnance Department, Naval Ordnance Test Station, Inyokern, California, and used extensively at NOTS since 1949.

6. Very low output impedance; large output voltage range, over which the foregoing criteria are satisfied.
7. Output and input of opposite algebraic signs, so that negative feedback results when output and input are connected through a passive impedance.

Operation of the amplifier of Figure 1, Page 25, relies upon a Type 6AU6 high-gain input pentode, and a direct-coupled Type 6BQ7A dual triode operated as a cathode-follower output stage. The composite load impedance of the output cathode follower is a series arrangement of a Type OA2 voltage regulator tube and one triode section of a Type 12AV7. Returned to a regulated source of - 300 volts, the second cathode follower maintains essentially constant plate current over a wide range of plate voltage. A high-level amplifier output voltage, which is balanced about zero for zero input voltage, is generated with respect to ground at the junction of the OA2 voltage regulator tube and the single triode section of the 12AV7. The second identical section of this dual triode serves a duplicate function for an adjacent operational amplifier.

The cathode of the input pentode is returned to a potential which can be varied up or down over a small range within a few volts of zero or ground potential. The COARSE DC BALANCE potentiometer establishes a net positive potential at the cathode, while the FINE DC BALANCE potentiometer permits sensitive control of cathode potential over a small range. In order to minimize input grid current and maintain very high gain over the desired operating range of $\pm$100 volts, the input pentode is operated with elevated screen potential and with plate load resistor and supply voltage of unusually high values. With circuit parameters as shown in Figure 1, Page 25, basic voltage gain of the pentode is approximately 1000.

If the control grid of the 6AU6 pentode is held at ground potential, the level of plate current is established by cathode potential under the control of the coarse and fine balance potentiometers. For any such cathode potential, corresponding to a fixed negative grid bias, the plate potential of the pentode is followed within a few volts by the cathode of the parallel-connected Type 6BQ7A dual triode. The potential of the amplifier output connection is lower by the nominally constant drop of 150 volts across the OA2 regulator tube.

An increase in cathode potential of the pentode, introduced by the coarse or fine balance potentiometers, is equivalent to greater negative grid bias, and increases plate potential. The identical increase in potential at the grids of the Type 6BQ7A dual-triode cathode follower output stage produces an almost equal rise in potential at the parallelled cathodes and also at the amplifier output connection. Similarly, a decrease in cathode potential of the 6AU6 results in a decrease in the potential at the amplifier output connection.

The normal operating point of the 6AU6 cathode is approximately + 2 volts. With the grid at ground potential, plate current will be approximately 60 microamperes and plate potential about 145 volts. With this value of grid potential on the 6B Q7A dual triode, its cathode potential will be approximately 150 volts. The potential at the amplifier output terminal will therefore be near zero. If amplifier output is found to be other than zero when the grid of the input pentode is grounded, a readjustment of 6AU6 cathode potential with one or both of the DC balance potentiometers will bring amplifier output to zero.

The COARSE DC BALANCE potentiometer can compensate for gross offset in amplifier output voltage at zero input voltage. The FINE DC BALANCE potentiometer has a much more limited range at the amplifier output, and is used for final, accurate setting of 6AU6 cathode potential in order to make zero amplifier output voltage correspond with zero potential on the input grid. Once this adjustment has been made, amplifier output voltage will be proportional to input grid voltage over an output range of ± 100 volts.

Operation of the amplifier of Figure 1, Page 25, has so far been described without reference to the positive feedback introduced and controlled by resistors R10 and R11, connected between amplifier output and the cathode of the input pentode. Suppose that a small positive voltage is applied at the amplifier input. The resultant increase in plate current of the 6AU6 will lower the potential of the 6AU6 plate and the direct-coupled 6BQ7A dual triode grids, and will give rise to a negative amplifier output voltage. The effect of the conductance through the series connection of R10 and R11 is to move the cathode of the input pentode in the same direction as the output. This is equivalent to a further increase in the potential of the input grid, and represents positive or regenerative feedback. The result is that less signal is necessary on the input grid to obtain a given output voltage. Increasing the conductance of the feedback path by decreasing R10 can increase positive feedback to the point of infinite gain, so that the ratio of output voltage to the initiating signal on the input grid increases without limit. Infinite gain can be achieved under one set of operating conditions, but the changes in tube characteristics over the operating range impose a practical limit on average gain at the extremes of the range.

Experimental measurements of output voltage versus input voltage for a typical amplifier in the Model 3000 Computer are shown graphically in Figure 2, Page 26. Infinite gain over the full operating range would be represented by the straight line $e_g = 0$, extending from - 100 volts output to + 100 volts output. The curve for the unloaded amplifier ($R_L = \infty$) shows that a maximum grid signal of 5 millivolts is required for operation over the full + 100 volt range, and that average gain over most of the range is much greater than 20,000. The lowest value of average gain under full load (R_L = 20,000 ohms) is 10,000 at full positive range, where a grid signal of 10 millivolts is required. Even under full load, average gain exceeds 30,000 over most of the operating range.

The amplifier of Figure 1, Page 25, is shown in symbolic form in Figure 3a, Page 27. As indicated in the diagram, the gain $\underline{A}$ is very high, and the input and output are of opposite algebraic sign.

When a high gain amplifier such as that of Figure 1 is used in an analog computer application, it is made an operational amplifier by the addition of two passive external impedances, as shown in the diagram of Figure 3b. One impedance, Z_i, is connected in series with the input driving voltage, e_i. The other impedance, Z_f, is connected directly between output and input of the high gain amplifier and therefore introduces negative feedback. In the schematic of Figure 1, Z_f would be connected between the bottom of the OA2 VR tube (upper output terminal) and the grid of the 6AU6.

With the addition of input impedance Z_i and feedback impedance Z_f, the gain of the amplifier of Figure 1 becomes virtually independent of all circuit parameters except Z_i and Z_f. The general case is illustrated in Figure 4, Page 28, where $\underline{n}$ separate input voltages, $e_1, e_2, e_3, \ldots\ldots e_n$, are fed to the amplifier input through $\underline{n}$ separate input impedances, $Z_1, Z_2, Z_3, \ldots . Z_n$. A single feedback impedance, Z_f, is connected directly between input and output of the high gain amplifier. Since input voltage, e_g, and output voltage e_o, of the amplifier have opposite algebraic signs, amplifier gain is defined by the equation

$$e_g\,(-A) = e_o.$$

If the input currents contributed by the separate input voltages are $i_1, i_2, i_3 \ldots i_n$, and if the feedback current is i_f, then continuity of current requires that

$$i_1 + i_2 + i_3 + \ldots . + i_n = i_f + i_g$$

where i_g is the current into the input grid. But

$$i_1 = \frac{e_1 - e_g}{Z_1} \;;\quad i_2 = \frac{e_2 - e_g}{Z_2} \;;\quad i_n = \frac{e_n - e_g}{Z_n}$$

and

$$i_f = \frac{e_g - e_o}{Z_f}$$

The current equation therefore becomes

$$\frac{e_1 - e_g}{Z_1} + \frac{e_2 - e_g}{Z_2} + \ldots \frac{e_n - e_g}{Z_n} = \frac{e_g - e_o}{Z_f} + i_g$$

Making use of the equation for amplifier gain the current equation may be rewritten

$$\sum_1^n \frac{e_i + e_o/A}{Z_i} = -\frac{e_o}{Z_f}\left(1+\frac{1}{A}\right) + i_g$$

As shown by the characteristic curves of Figure 2, Page 26, the value of amplifier gain, A, is 10,000 or more over the full range of operation at maximum rated load. Terms with the coefficient 1/A may therefore be neglected in comparison with unity or with normal values of e_i. In addition, the value of grid current in the amplifier of Figure 1 has been found to lie consistently under 1 millimicroampere ($< 10^{-9}$ amp) under all normal operating conditions. Since other currents in the equation above will nearly always lie between one hundred and five million times this value, i_g may be safely neglected. The resulting equation

$$e_o \doteq -\sum_1^n e_i\left(\frac{Z_f}{Z_i}\right)$$

shows that circuit parameters of the high gain amplifier do not enter the expression for gain of the operational amplifier. Instead, gain for each input voltage is determined by the ratio of the feedback impedance to its particular series input impedance.

The various functions which may be served by the generalized operational amplifier of Figure 4, Page 28, are accomplished by using appropriate input and feedback impedances. For algebraic summing of input voltages, sign changing, and multiplication or division by a constant, the feedback impedance Z_f and all input impedances Z_i are resistors. These operations are illustrated in terms of specific examples in the diagrams of Figures 5, 6 and 7, Pages 29-31. In practical operation, the ratio R_f/R_i is not allowed to exceed 20.

For the important process of integration, the feedback impedance Z_f is a capacitor and the input impedances are resistors.* The characteristic operation of such an arrangement can be seen clearly in terms of the simple integrator of Figure 8, Page 32. Since $i_g = 0$, the current through the input resistance R_i is continuous with the charging current on the feedback capacitor C_f.

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*For this case, using operational calculus nomenclature, the generalized operational amplifier equation $e_o = -\sum_1^n e_i (Z_f/Z_i)$ becomes

$$e_o = -\sum_1^n e_i\left(\frac{1}{C_f p}\Big/R_i\right) = -\sum_1^n \frac{1}{R_i C_f} \times \frac{e_i}{p}$$

The output voltage is therefore the summation of the time integrals of the input voltages.

If the voltage across the capacitor is V and its instantaneous charge is q(t), the charging current is

$$i(t) = \frac{dq(t)}{dt} = \frac{d(VC_f)}{dt} = C_f \frac{dV}{dt}$$

But the negative feedback operation of the high gain amplifier is such as to keep $e_g \doteq 0$, so that the input grid is essentially held at ground potential for any normal value of output voltage. The current equation therefore becomes

$$\frac{e_i}{R_i} = C_f \frac{dV}{dt} = -C_f \frac{de_o}{dt}$$

It follows that

$$e_o = \frac{-1}{R_i C_f} \int_0^t e_i \, dt + e_o \Big]_{t=0}$$

The arbitrary constant of integration $e_o \Big]_{t=0}$ is supplied by the voltage across C_f when t = 0.

These principles may be readily extended to the summing integrator of Figure 9, Page 33. Again, since $i_g \doteq 0$, the total input current is continuous with charging current on the feedback capacitor. Therefore, since $e_g \doteq 0$, the current equation is

$$\sum_1^n \frac{e_i}{R_i} = C_f \frac{dV}{dt} = -C_f \frac{de_o}{dt}$$

Solving for the output voltage

$$e_o = -\frac{1}{C_f} \int_0^t \sum_1^n \frac{e_i}{R_i} \, dt + e_o \Big]_{t=0}$$

showing that the output is the sum of the time integrals of the input voltages, with sign inverted. The use of an operational amplifier as a summing integrator is illustrated quantitatively in the diagram of Figure 10, Page 34. Since R_i and C_f always appear as a product, megohms and microfarads may be substituted directly into the equations in lieu of ohms and farads.

Operational amplifiers may be used under restricted circumstances to form derivatives of applied voltages. However, because special precautions must be observed to avoid instability, their use for this function is not recommended. Fortunately, it is rarely necessary to employ an operational amplifier as a differentiator in the normal course of solving differential equations with the electronic analog computer.

Solution of Differential Equations

By means of more complicated input and feedback impedances, single operational amplifiers may serve a large variety of other special functions, such as the generation of the electrical analogs of Laplace transforms. However, their basic role in the Model 3000 Analog Computer involves their use in combination to solve differential equations. A typical simple problem which recurs frequently in such fields as mechanical vibration, circuit analysis, and control systems is the solution of a general second order differential equation, which is often expressed as follows:

$$\frac{d^2\theta_o}{dt^2} + 2\rho\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = \omega_n^2\theta_i$$

To solve such a problem with the Model 3000 Computer, a formal procedure* may be adopted in which it is assumed that an input signal representing $\frac{d^2\theta_o}{dt^2}$, the highest derivative, is available to a specified operational amplifier in the computer. If this amplifier is connected as an integrator, then its output voltage will be proportional to the next lower derivative (with sign reversed), $-\frac{d\theta_o}{dt}$. This voltage may serve as input to the next operational amplifier, again connected as an integrator. Its output will represent θ_o, the dependent variable.

The highest derivative in the differential equation to be solved by the computer may be expressed mathematically in terms of lower derivatives, the dependent variable itself, and the driving function. In the present example

$$\frac{d^2\theta_o}{dt^2} = +\omega_n^2\theta_i - 2\rho\omega_n\frac{d\theta_o}{dt} - \omega_n^2\theta_o$$

As a final step in setting up the computer to solve the problem, the highest derivative is so expressed in circuit form. Lower order terms are taken from the amplifier outputs where they are assumed to be generated through the integration process. The input driving function is supplied from an

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*Detailed information on theory and procedures in the use of operational amplifiers for the electronic analog solution of physical problems is given in the book, "Basic Theory of the Electronic Analog Computer" by Dr. R. C. H. Wheeler. This book, published by Donner Scientific Company, is available to users of Model 3000 Computer equipment.

external function generator or is synthesized by other operational amplifiers in the computer. All terms are combined in the proportions specified by the differential equation, and are fed together into a summing amplifier. Any necessary changes of algebraic sign are introduced by additional individual operational amplifiers, output and input of each amplifier being of opposite sign. The output of the summing amplifier is then connected to the amplifier input where the highest derivative was first assumed to be introduced.

An arrangement of operational amplifiers to solve the second order differential equation written above is shown in Figure 11, Page 35. As shown there, the highest derivative is synthesized in the proportions specified by the differential equation. In this way, the unique requirements of the equation are imposed on the solution delivered by the computer.

In order to generate the correct definite integral at the output of each operational amplifier connected as an integrator, it is necessary to apply the initial condition voltages which correctly define the various constants of integration. These voltages are maintained by separate sources until the time $t = 0$; then the voltage sources are simultaneously disconnected and the problem is released to the computer for solution.

Functional Arrangement

The Model 3000 Computer is comprised of three basic sections: the Amplifier Section, the Power Supply Section, and the Cabinet. As shown in the front-page photograph of Donner Model 3000 Brochure, the Amplifier Panel and Power Supply Panel are respectively the upper and lower sections of the complete computer, and are housed in its cabinet. The completely detachable Problem Board, a separate item, plugs into two multi-conductor connectors near the bottom of the Power Supply Panel, and is normally supported by the surface on which the computer is set (desk or table-top).

Amplifier Section

The Amplifier Section contains the ten operational amplifiers of the computer, arranged side-by-side on a single chassis. As shown in the top view of the Amplifier Section inside the Model 3000 Brochure, the COARSE BALANCE controls are arranged in a row along the back. Next in order toward the front of the chassis is the row of 6AU6 input pentodes; the 6BQ7A output dual triodes; the row of GAIN setting potentiometers; the OA2 voltage reference tubes; and the 12AV7 dual triodes, each of which is shared between two amplifiers.

The front panel of the Amplifier Section is furnished with a variety of controls for both selection and adjustment, and a 4 1/2" zero-center meter which serves two main indicating functions. In addition, a row of lights near the top of the panel serve as individual indicators of actual or impending overload for the ten operational amplifiers.

Arranged in a row just below the overload lights are the amplifier FINE BALANCE controls. To the right of the meter, which is centered in the lower part of the panel, is the function selector and meter range switch. To the left of the meter is the amplifier selector switch. Terminals for connecting to an oscilloscope or other high-impedance readout device are located below the selector switch on the right.

The purpose of the amplifier selector switch is to connect the meter circuit to any one of the ten operational amplifiers for the functions of adjustment or indication, available on the selector switch at the right. The function and range selector switch has seven positions: Proceeding clockwise, the first three concern adjustments of the selected amplifier, and the last three involve range switching of the meter, which is then connected to the amplifier output; the center position disconnects the meter from the selected amplifier, but leaves the amplifier output connected to the output jacks below the selector switch.

Gain Adjustment

Again proceeding clockwise, the first position on the function and range selector switch is marked GAIN. As shown on the schematic, Drawing 823, the operational amplifier selected by the selector switch on the left is automatically connected as shown in Figure 12, Page 36. A 60-cycle signal of 50 volts peak-to-peak is applied to the amplifier, connected as a sign changer with gain of unity. The resulting grid signal is brought to the output jack labeled AMPLIFIER INPUT, and the corresponding output signal is connected to the output jack labeled AMPLIFIER OUTPUT. If these output jacks are connected respectively to the vertical and horizontal inputs of an oscilloscope with high Y-axis gain, the resulting trace will be a straight line having an inclination related to amplifier gain. Infinite gain is indicated by a horizontal trace, since no grid signal is required for an output excursion up to $\pm$ 25 volts. For less than infinite gain, a finite grid signal of perhaps 2 or 3 millivolts will be required for an amplifier output of 25 volts.

The GAIN adjusting potentiometers located in the center of the amplifier chassis have a range of adjustment which extends beyond infinite gain. Under such circumstances, the slope of the trace on the oscilloscope screen is reversed, a positive-going input signal producing a positive-going output signal. As the characteristic curves of Figure 2, Page 26, confirm, the desired gain setting of each operational amplifier corresponds to "infinite" gain of the unloaded amplifier over an output range of ± 25 volts or more. Gain setting can therefore be made by adjusting for a horizontal oscilloscope trace as described above.

Balance Adjustments

The second and third positions of the function and range selector switch are marked COARSE and FINE, respectively, corresponding to coarse and fine balance adjustments of the amplifier selected by the amplifier selector switch on the left. Setting of the right-hand selector switch to COARSE connects the amplifier as shown in Figure 13, Page 37. As an operational amplifier with input voltage at IN and output voltage at OUT, amplifier gain is set at a fixed value of 10 by the ratio of feedback to input resistance. (See Figures 4, 5, 6, 7.) The input terminal of the amplifier is connected directly to ground potential, so that no external input voltage is introduced. As shown in Figure 1, and as discussed in the earlier section on Operational Amplifiers (see Page 4), the potential of the amplifier output terminal may then be adjusted to zero or ground potential by properly positioning the cathode potential of the 6AU6 input pentode. (Note that the problem board must be removed during the balancing operation). This is the function carried out on the selected amplifier by adjusting the setting of the corresponding COARSE DC BALANCE or FINE DC BALANCE controls, when the function selector switch at the right side of the amplifier panel is set on COARSE or FINE.

Figure 13, Page 37, shows that when the function selector switch is set on COARSE, the indicating meter on the amplifier panel is connected to read 20 volts full-scale across the amplifier output. Since the amplifier is connected for a gain of 10 and has no external input voltage, the ± 20 volt output range corresponds to ± 2 volts equivalent input signal due to unbalance.

If the cathode of the 6AU6 input pentode is far from its proper potential the COARSE DC BALANCE potentiometer at the rear of the amplifier chassis must be adjusted to bring amplifier balance within range of the FINE DC BALANCE control on the amplifier panel. At the same time, the meter reading of the output voltage can be reduced within the ±1 volt range of the FINE position of the function selector switch, shown as the alternate switch position on Figure 13. At an amplifier gain of 10, the output range of ± 1 volt corresponds to an equivalent input signal range of ± 100 millivolts. One minor division on the meter scale is then 20 millivolts, which represents 2 millivolts at the amplifier input. Using the FINE DC BALANCE adjustment and the FINE position of the function selector switch, amplifier unbalance may reasily be reduced below 2 millivolts for a gain-of-ten amplifier.* Drift characteristics of the ten operational amplifiers of a typical Model 3000 Computer on the second full day of operation are shown in Figure 14, Page 58. The drift per hour is shown to be less than 4 millivolts in all cases.

Meter "OFF" and Output Range Switching

The first three positions of the function and range selector switch concern adjustment of the selected amplifier, preliminary to normal use for computing functions. The remaining four positions relate to amplifier output indication in normal use.

In the first of these four switch positions, the panel meter is entirely disconnected from amplifier output. However, the output voltage of the selected amplifier remains connected to the AMPLIFIER OUTPUT and GROUND jacks below the function selector switch, so that connection may be made to an external high-impedance indicator or recorder.

The three other positions of the function and range selector switch connect the panel meter across the output of the selected amplifier, with full-scale range indications of ± 100 volts, ± 20 volts, and ± 2 volts, respectively. In all cases, the output terminals of the selected amplifier remain connected to the output jacks below the right hand selector switch.

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*If the potential at the amplifier output is e_o above ground due to unbalance and the input terminal is connected to ground as shown in Figure 13, a current $\frac{e_o}{R_1 + R_f}$ must flow between the amplifier output and ground (since $i_g = 0$). The voltage rise of the grid terminal with respect to ground will then be

$$e_g = \frac{R_i}{R_i + R_f} e_o \text{ (UNBALANCE)}$$

The actual grid-terminal unbalance associated with a particular unbalanced output is, therefore, less than the output meter reading by the factor $\frac{R_i + R_f}{R_i}$. In the Model 3000, this factor is approximately 11.

As an output indicator, the panel meter is of value as a monitor and as a quantitative readout means for data, within its limited speed of response. For more rapidly varying output data, quantitative presentation may be made visually on an oscilloscope or graphically on a high-impedance pen recorder connected between the AMPLIFIER OUTPUT and GROUND jacks, below the function and range selector switch.

Power Supply Panel

The Power Supply Section contains the main regulated power supplies for the operational amplifiers, the separate regulated initial condition power supplies with their output controls, the relays participating in computing operations, and the connectors which carry supply voltages to the amplifiers and conduct the computing functions to the Problem Board. Top and bottom views of the Power Supply Section are shown in photographs inside the Model 3000 Brochure. As shown in the top view, the right-hand half of the chassis contains the high voltage transformer and the regulating circuitry of the negative and positive power supplies for the ten operational amplifiers. The filament transformer near the front panel supplies all of the pilot lights and all of the heaters which do not require regulation. On the left rear is the VR transformer which supplies a regulated voltage for the heaters of the 6AU6 input pentodes of the operational amplifiers. Directly in front of the VR transformer is a dual vacuum diode, Type 6AL5, whose plate and cathode connections are terminated on the problem board.

Adjacent to the VR transformer is a transformer with five isolated secondary windings for the five separate initial condition voltages, and a sixth secondary for energizing the COMPUTE-RESET and the HOLD-OPERATE relays. Next in order toward the panel are parallel rows of filter capacitors and OB2 voltage regulator tubes. Five of these tubes operate in conjunction with five dry-disc rectifier stacks mounted beneath the chassis; these deliver five independent, regulated DC voltages for the Initial Condition Power Supplies. The Type OA2 and its associated rectified stack furnish a regulated booster voltage, which is added to the positive output of the main power supply to serve as the plate supply for the computer amplifier 6AU6 input pentodes. The seventh rectifier stack shown beneath the chassis furnishes DC voltage for operation of the five relays; the latter are located in a cluster below the chassis and near the output connector. As shown on the schematic, Drawing 825, the two COMPUTE-RESET relays are operated by the plate current of a 6CL6 pentode, and are thrown simultaneously from RESET to COMPUTE by shorting the grid to ground potential. The HOLD-OPERATE relay is controlled directly by the operating switch. Its action is to open individual circuits to five of the ten relay poles used for the COMPUTE-RESET operation.

Three multi-conductor plugs terminating three short cables mate with three corresponding connectors in the left lower edge of the Amplifier Chassis, and make all necessary interconnections between Amplifier and

Power Supply Panels. In order of their arrangement from front to rear, the first connector carries amplifier output leads; the second carries amplifier input leads; and the third carries all power wiring. Physical separation of the low level amplifier input wiring from both the high level amplifier output wiring and from the AC power wiring facilitates the reduction of amplifier crosstalk and 60-cycle hum in computer operation.

The front panel of the Power Supply Section is provided with four toggle switches and their associated pilot lights, five controls and five associated pairs of output jacks, and the connectors which receive the detachable problem board. The FILAMENT switch at the left controls all vacuum tube heaters and provides an interlock for all other services. The PLATE switch at the right controls the generation of high voltage, including voltages for the Initial Condition Power Supplies, and also provides interlock features as shown in the schematic, Drawing 824. The second switch from the left controls the HOLD-OPERATE relays, and the third controls the COMPUTE-RESET relays. The five controls just below the switches set the output voltages of the five Initial Condition Power Supplies. The two output terminals of each Initial Condition Power Supply are located below the control which sets its voltage level.

Near the lower edge of the panel are the two multi-conductor connectors which carry the amplifier, relay, and certain accessory connections to the Problem Board. In order to minimize crosstalk between amplifiers, all the amplifier input wiring is routed through the connector at the left, while the connector at the right carries all the interwiring from the amplifier outputs. For the same reason the ten COMPUTE-RESET relay poles are divided into two equal groups which are routed separately through the two connectors. The five poles and associated double-throw contacts which are affected by the HOLD-OPERATE relays are allocated to low-level or input functions, and are routed through the left-hand connector. The other five poles and associated double-throw contacts are allocated to high-level or amplifier output functions, and are routed through the right-hand connector.

On the rear face of the Power Supply chassis, and accessible through the back of the computer cabinet, are the three-wire AC input connections, two fuse post assemblies (one for each side of the line), accessory AC outlets, the + 370 volt and - 300 volt test terminals, and signal terminations for computer accessories.

Main Computer Power Supplies

The main positive and negative high voltage power supplies for the operational amplifiers are individually electronically regulated to approximately 0.25% for line voltages from 105 to 125 volts and amplifier loads up to 5 milliamperes. The negative supply, which delivers a regulated voltage of - 300 volts at an essentially constant load current of 130 milliamperes, is controlled with respect to the voltage drop across a Type OA2 glow-discharge tube operated at constant current. The positive voltage supply uses the regulated voltage output of the negative supply as a reference, and delivers a regulated output of + 370 volts at load currents up to 180 milliamperes.

The two main power supplies make use of electronic regulators which are very similar to the high gain DC amplifier of Figure 1, Page 25. Each makes use of a 6AU6 input pentode direct-coupled to a dual-triode cathode follower output stage. As shown in the schematic, Drawing 824, the cathode of the 6AU6 which regulates the negative power supply is kept at a potential 150 volts above the negative high voltage output by the fixed drop across the OA2 voltage reference tube. A voltage divider across the entire output voltage of the supply is formed by the series arrangement of R125, R124 and R126. A connection near the center of this divider is carried back to the control grid of the 6AU6 pentode. By the same negative feedback action as in the arrangement of Figure 3b, the combined action of the 6AU6 and the following 6080 double-triode cathode follower is to keep the potential at the arm of R124 very close to cathode potential of the 6AU6. This is brought about by sensitive control of the series impedance of the 6080. But since the voltage between the negative high voltage terminal and the arm of R124 is developed by current which is continuous through R125, R124 and R126, the entire negative output voltage is regulated at a value which depends on the resistance ratio of the divider. The division ratio may be varied and the regulated negative output voltage adjusted over a limited range by varying the position of the slider of R124.

The electronic regulator for the positive voltage supply behaves just as described above. However, it bears even more resemblance to the amplifier of Figure 3b than the regulator for the negative supply. The cathode of the input pentode is operated at ground potential. The series input resistance corresponding to R_i is R113. The feedback resistance corresponding to R_f is R112. The voltage input corresponding to e_i is - 300 volts from the negative supply, serving now as a reference voltage. The + 370 volt power supply is slaved to the - 300 volt supply and need not be adjusted independently. The output of the - 300 volt supply can be adjusted by potentiometer R124 (screwdriver-adjustment type), mounted at the rear of the power supply chassis.

Through the negative feedback action of the high gain amplifier, the potential of the slider of R111 (connected to the 6AU6 grid) will be maintained very close to cathode or ground potential. Therefore, the voltage output appearing across R_f will be regulated to the value e_i (R_f/R_l). The ratio (R_f/R_l) sets this voltage to + 370 volts.

In each regulated supply, the direct and feedback connections to the screen grid of the 6AU6 (R108 in the positive supply, R121 in the negative supply) are both in a direction to oppose the change in plate potential brought about by change in line voltage. By proper choice of component values, screen grid control is thereby used to augment the regulation brought about by the 6AU6 control grid.

Computer Cabinet

The sheet-metal computer cabinet mounts the two standard 8 3/4" panels of the Amplifier and Power Supply sections. It is provided with a removable back, which gives access to tubes and adjustments within the computer. In addition, the removable back supports the ventilating fan.

Problem Board

The Problem Board provides connections between operational amplifiers and specific external computing elements which generate the electrical analogs of differential equations to be solved. Connections from the inputs of all amplifiers are brought through the mated connector pair at the left of the computer to the corresponding input terminals in the circuit representation of the amplifiers on the problem board. Connections from all amplifier outputs are routed through the connector pair on the right of the computer to corresponding output terminals in the circuit representation on the problem board. Input and output wiring runs are kept separated, even in the problem board, in order to minimize crosstalk from the high-level output of one amplifier to the low-level input of another. Input and output connections to one Model 3730 Electronic Function Multiplier and one Model 3750 Variable Base Function Generator are available on the Model 3034 and 3033 Problem Board (Illustrated in Drawing 850). In addition, a dual-vacuum diode (6AL5) is mounted in the power supply chassis, and both plate and cathode connections are terminated on the Model 3033 and 3034 Problem Boards.

Poles of the COMPUTE-RESET relays are brought by two routes to their terminals in the circuit schematic on the problem board. The five poles and associated double-throw contacts which are affected by the HOLD-OPERATE relays and are allocated to low-level or input functions are routed with the amplifier input wiring through the connector on the left. In the circuit representation of the relays in the upper central section of the problem board, terminal connections for these five low-level relay poles occupy odd-order positions 1, 3, 5, 7 and 9, reading from the left. The remaining relay poles and associated contacts, which are allocated to high-level or output functions, are routed with the amplifier output wiring through the connector on the right. In the circuit representation of the relays on the problem board, terminal connections for these high-level relay poles occupy even-order positions 2, 4, 6, 8 and 10.

Each problem board is furnished with a bottom cover plate, which serves as a shield and reduces AC hum on any amplifier output to an unimportant level. The bottom plate also provides four support points, on which the board rests when it is plugged into the computer.

The Model 3034 Problem Board is equipped with jack type terminals. The Model 3033 Problem Board is instead equipped with solder type terminals. Jacks are spaced three-fourths inch between centers, and are located and connected as shown in Drawing 850.

OPERATING INSTRUCTIONS

Procedure for Computer Set-Up

Initial set-up and adjustment of the Model 3000 Computer should be carried out with the problem board completely detached, or alternatively, with no connections made to the amplifier terminals on the board.

With the PLATE and FILAMENT switches in the OFF (down) position, attach the line cord at the lower rear of the computer cabinet and plug it into a source of 105-125 volts, 60 cps AC, (or 230 volts, 50cps, if so ordered). Turn the FILAMENT switch ON and allow the vacuum tube heaters to warm up for one minute before turning on the PLATE switch. After turning the PLATE switch ON, allow the computer to warm up for at least an hour before making final balance or gain adjustments on the operational amplifiers.

The power supply voltages of + 370 and - 300 are not likely to require adjustment, but may be set by means of the slotted-shaft potentiometer on the rear of the power supply chassis. This potentiometer (R124 on schematic Drawing 824) sets the - 300 volt level. The + 370 volt supply is "slaved" to the negative supply and will not require readjustment.

If the problem board is disconnected, or if no connections are made to amplifier terminals on the board, balance and gain adjustments may be made with the HOLD-OPERATE and the COMPUTE-RESET switches in any position. Balance and gain adjustments of the amplifiers are largely independent. However, it is recommended that all amplifiers be brought approximately to balance before gain settings are made. The gain adjustment is very stable, and need be made only infrequently. Fine balancing may then be carried out just before the computer is used for problem solution.

Wire-wound Type, 1% or 0.1% Tolerance:

100,000 ohms	500,000 ohms
200,000 ohms	1 Megohm

Fixed Capacitors

Types: Polystyrene or Mylar Dielectric
Values: 0.01 mfd
0.1 mfd
1.0 mfd

Coefficient Potentiometers

Types: Single-turn Composition or Multi-turn Wire-wound; All 100,000 ohms.

As described previously in the section on Operational Amplifiers, fixed resistors are used for both input and feedback impedances in processes of algebraic summing, sign changing, and multiplying or dividing by a constant factor, as illustrated in Figures 5, 6 and 7, Pages 29 - 31. In addition, fixed resistors are used as input impedances when operational amplifiers are used for integration, as illustrated in Figures 8, 9 and 10, Pages 32-34. Fixed capacitors are used as the feedback impedance C_f of such integrators. The range of component values given above permits the selection of gain factors R_f/R_i and of integrator time constants $1/R_iC_f$ over a wide range. The ratio R_f/R_i should not be allowed to exceed 50, and should be 20 or less for maximum accuracy.

Coefficient potentiometers are commonly used across the outputs of operational amplifiers. One common reason is to increase solution accuracy by permitting the amplifier to operate over most of its full range, even though only a fraction of full voltage is required for the following operation. Another purpose is to derive a specified fraction of the total voltage which represents a variable, in the process of synthesizing the highest order derivative for initial problem set-up.

The important parameter introduced by a coefficient potentiometer is a voltage ratio, established by the position of the variable arm. However, the actual voltage attenuation coefficient, which must be accurately known for an accurate problem solution, depends upon the resistive load connected between the variable arm and ground potential. Such a load is normally applied by the input resistor of an operational amplifier. Actual potentiometer coefficients may be set or read accurately to three significant figures by the use of the Model 5000 Null Voltmeter. See the Instruction Sheet on Potentiometer Strips Models 3071 and 3073 at the end of this Handbook.

Initial Condition Voltages: Set-Up and Measurement

Each operational amplifier used as an integrator in the solution of a differential equation requires an associated initial condition voltage which is the analog of the arbitrary constant of integration. As shown in Figures 8, 9 and 10, Pages 32, 33 and 34, the initial condition voltage is applied across the integrating capacitor, and is maintained until its sudden release at t = 0, when the problem is released to the computer for solution.

The five independent, adjustable Initial Condition Power Supplies of the Model 3000 Computer furnish five regulated DC voltages which may be used as initial conditions, driving functions, or for other purposes as required. When one of the supplies is used to furnish an initial condition voltage, the output is connected across the feedback capacitor of the integrator concerned, and therefore establishes the output voltage at t = 0. Initial condition voltages may therefore be read or adjusted with the aid of the panel meter by selecting the operational amplifier concerned and reading its output voltage. However, a much more accurate setting or measurement is possible with the Model 5000 Null Voltmeter. Change in polarity of the initial condition voltage is introduced by reversing connections to the output terminals on the Power Supply Panel.

Use of the COMPUTE-RESET Relays

When the problem board connectors are engaged, the operation of the COMPUTE-RESET switch involves the relay terminals at the upper center of the board. When the COMPUTE-RESET switch is in RESET position the relays are unenergized, and the contacts are as shown in Drawing 850: the center contact of each relay pole is connected with the contact just above it on the problem board. No connection is made with the lower relay contacts on the board. When the switch is thrown to COMPUTE, the center contact of each relay pole is disconnected from the upper contact and connected with the lower.

The action of the COMPUTE-RESET relays described above is used to maintain an independent initial condition voltage across the feedback capacitor of each operational amplifier used as an integrator, until the time when the problem is released to the computer for solution. Thereupon the function of the COMPUTE-RESET relays is to disconnect each integrating capacitor from its Initial Condition Power Supply, and to connect the input of each operational amplifier used as an integrator to the proper driving point in the circuit analog.

Proper use of relay connections on the problem board is illustrated in Figure 14, Page 38:

1. Two relay poles are allocated to each integrator in the problem set-up: one marked IN for use in the low-level amplifier input circuit, and the other marked OUT for use in the high-level amplifier output circuit.

2. The center connection of the relay pole marked IN is connected to the integrating capacitor on the input side of the amplifier, and the center connection of the relay pole marked OUT is connected to the integrating capacitor on the output side of the amplifier.

3. The upper contact of each relay pole is connected to the Initial Condition Power Supply.

4. The lower contact of the IN relay pole is connected to the point in the analog circuit which must be connected to the input of the integrating amplifier during problem solution. The lower contact of the OUT relay pole is not required for the functions under discussion.

While the COMPUTE-RESET switch is in RESET position, Figure 14, Page 38, shows that the voltage from the Initial Condition Power Supply is maintained across the integrating capacitor. When the switch is thrown to COMPUTE position, connections to the Initial Condition Power Supply are broken, and amplifier input is connected normally for problem solution.

Use of the HOLD-OPERATE Relays

During normal RESET or COMPUTE operations as described above, the HOLD-OPERATE switch is kept in the OPERATE position. As shown in the schematic, Drawing 850, the HOLD-OPERATE relays remain unenergized in this switch position, and in terms of Figure 14, the center terminal of each relay group designated IN on the problem board is directly connected to the pole of the relay. However, when the HOLD-OPERATE switch is thrown to HOLD, the associated relays are energized and the center terminal of each relay group designated IN on the problem board is disconnected from its COMPUTE-RESET relay pole by the opening of the switch designated H.

The HOLD function is used when problem solution is to be interrupted temporarily (for examination or change of parameters or scale) and then resumed to completion. Observance of proper connections to the COMPUTE-RESET relays as shown in Figure 14, Page 38, insures proper operation of the HOLD-OPERATE relays. Since the HOLD function is used only while the COMPUTE-RESET switch and relay poles are in COMPUTE position, Figure 14 illustrates that HOLD operation interrupts the charging current input to each integrating capacitor so that integrator outputs remain unchanged. The computer solution proceeds when the HOLD-OPERATE switch is returned to OPERATE position.

Multiple Operation

Two or more Model 3000 Computers may be used together as a single large computer. To synchronize the COMPUTE-RESET and the HOLD-OPERATE functions, connect the four terminal receptacles (J114) located on the rear of the power supply chassis in parallel for all computers. Operation of either the COMPUTE-RESET switch or the HOLD-OPERATE switch of any one computer than produces simultaneous operation of the selected function in all computers. (This cable is not normally supplied with the Model 3000).

To operate two Model 3000 Computers in the fashion described above or to operate two Model 3000 Computers from a single Model 3720 Cyclic Reset Generator, a special interconnecting cable (Model 3720, Cable No. 569) may be obtained from the factory.

Amplifier Drift Stabilization

Where greater accuracy requirements or long computing intervals necessitate the use of stabilized computing amplifiers, the Model 3760 Chopper Stabilizer may be connected to one existing Model 3000 Computer to greatly reduce the drift of each of the ten operational amplifiers. The Model 3760 is usually placed between the amplifier and power supply chassis of the computer.

SERVICING

Except for the renewal of fuses, pilot lights or tubes, servicing should be referred to the nearest Donner Scientific Company representative.

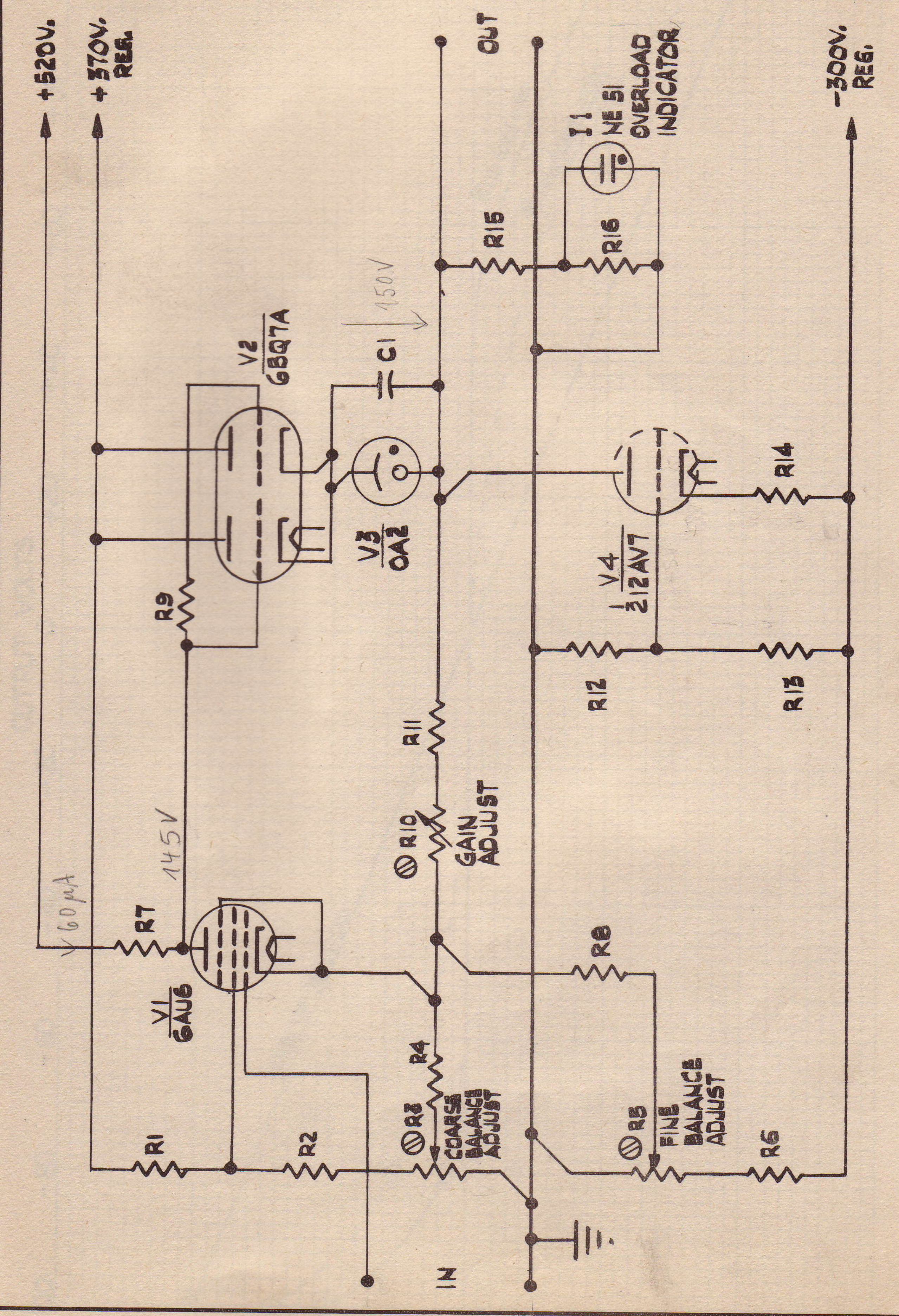


Figure 1: Model 3000 High Gain DC Amplifier, Schematic Diagram

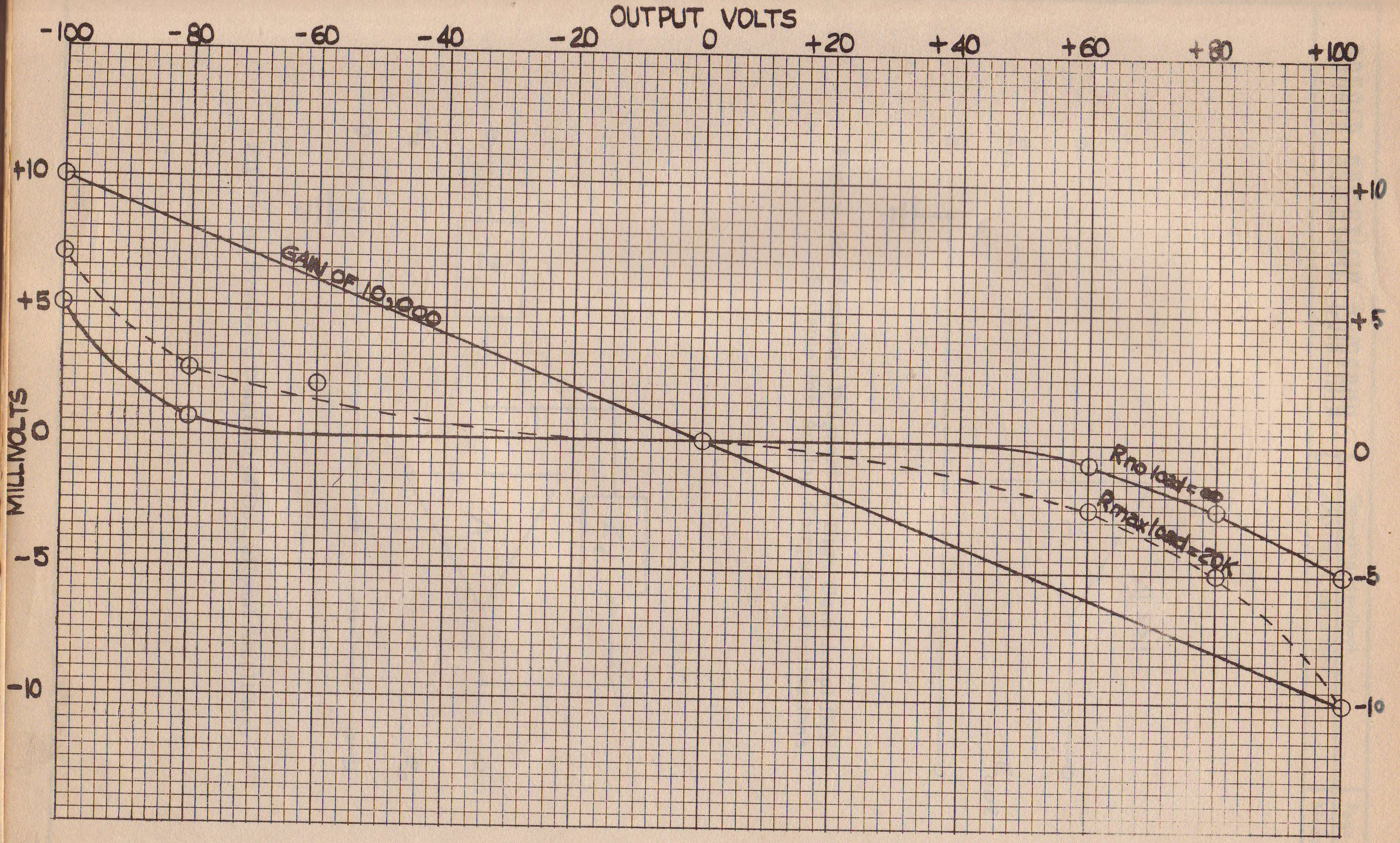


Figure 2: Amplitude Transfer Characteristic of Typical Operational Amplifier, Model 3000 Computer

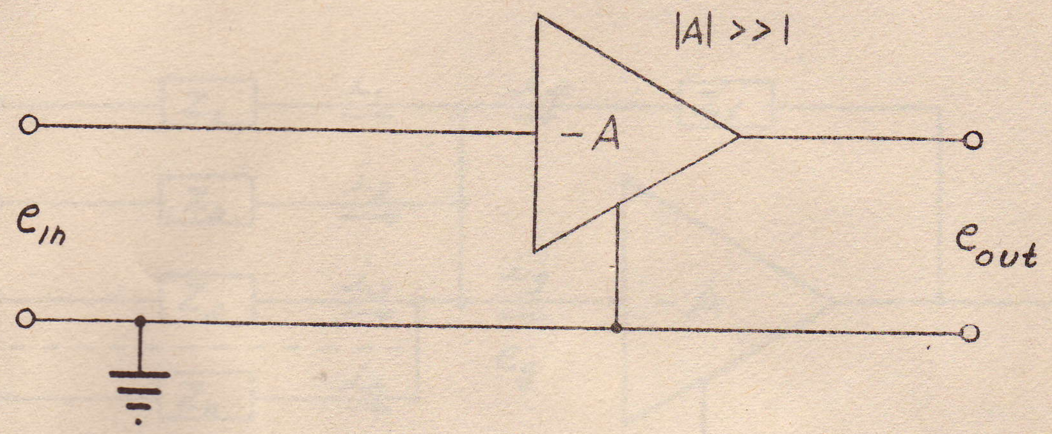


Figure 3a: Symbolic Diagram of High Gain Amplifier Suitable for Analog Computer Applications.

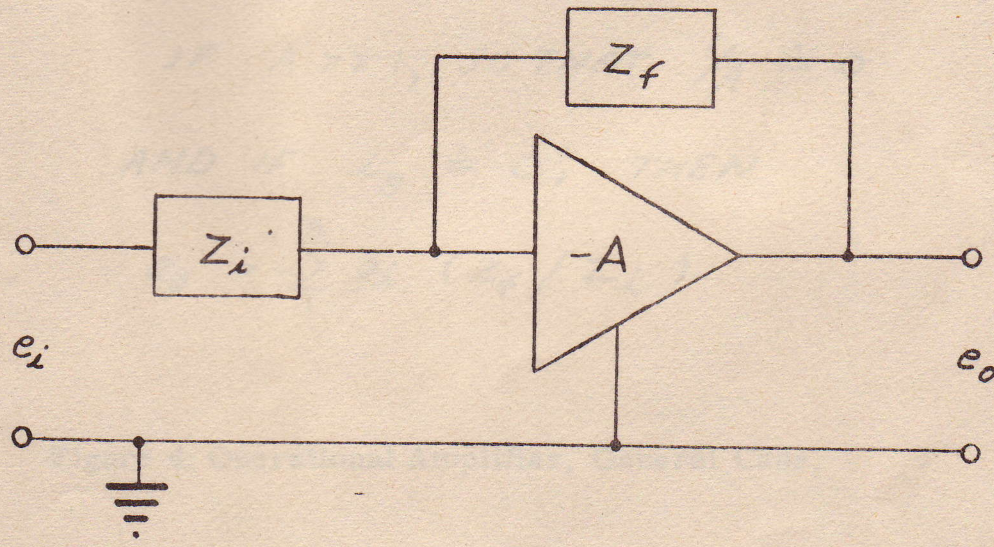
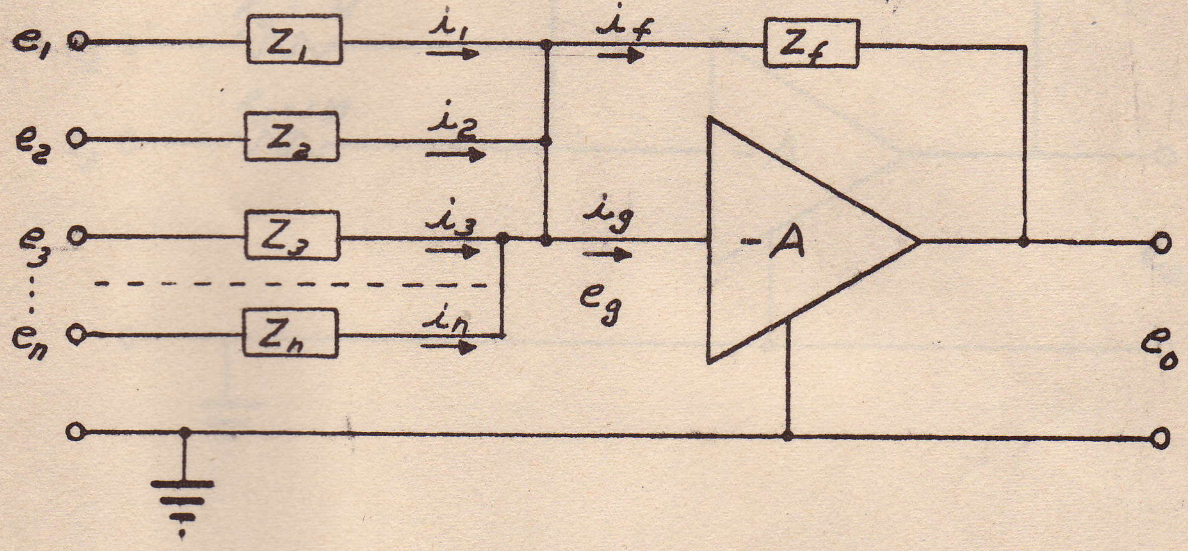


Figure 3b: Symbolic Diagram of Operational Amplifier.

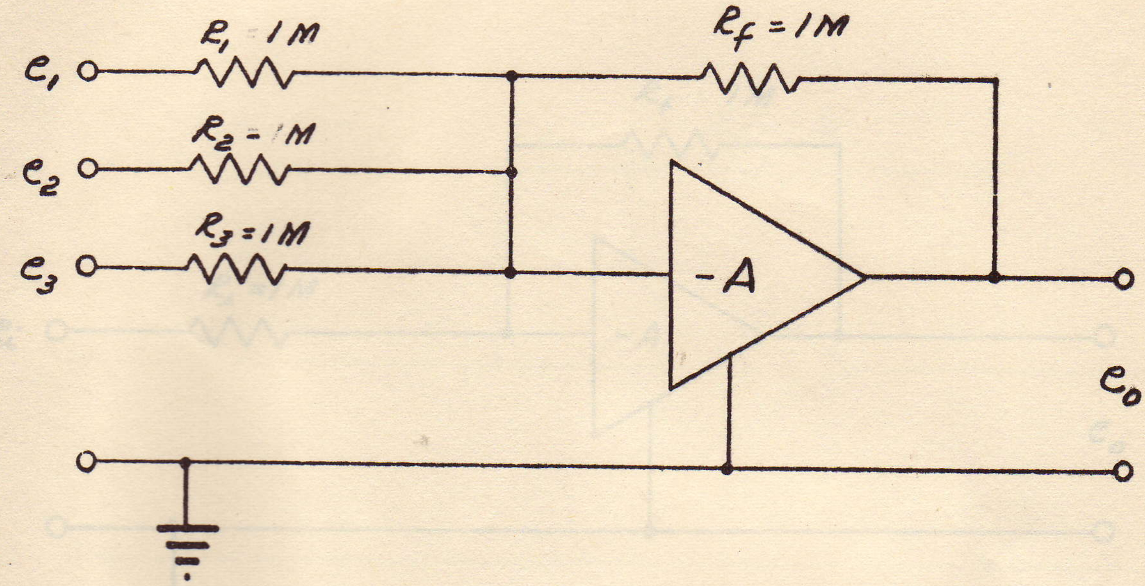


IF $A >> 1$, SO THAT $1/A \doteq 0$

AND IF $i_g \doteq 0$, THEN

$$e_0 = -\sum_{1}^{n} e_i \, (Z_f / Z_i)$$

Figure 4: Operational Amplifier, General Case.



$$e_o = -\left(e_1\frac{R_f}{R_1} + e_2\frac{R_f}{R_2} + e_3\frac{R_f}{R_3}\right)$$

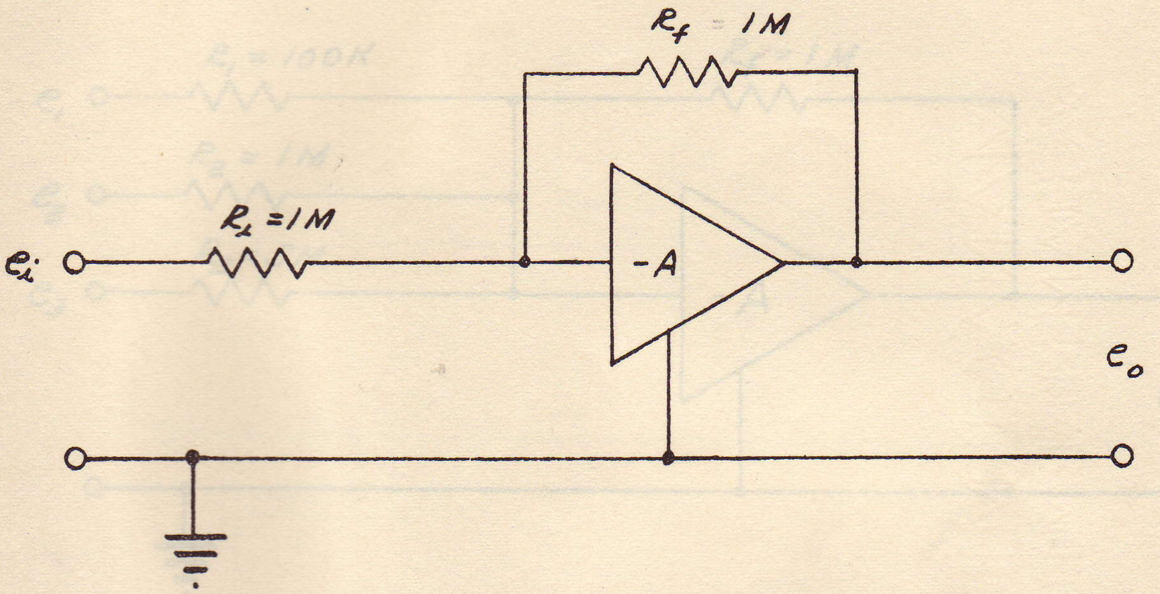
$$= -(e_1 + e_2 + e_3)$$

IF $e_1 = 20$ VOLTS, $e_2 = 75$ VOLTS,

$e_3 = -30$ VOLTS

$$e_o = -(20 + 75 - 30) = -65 \text{ VOLTS}$$

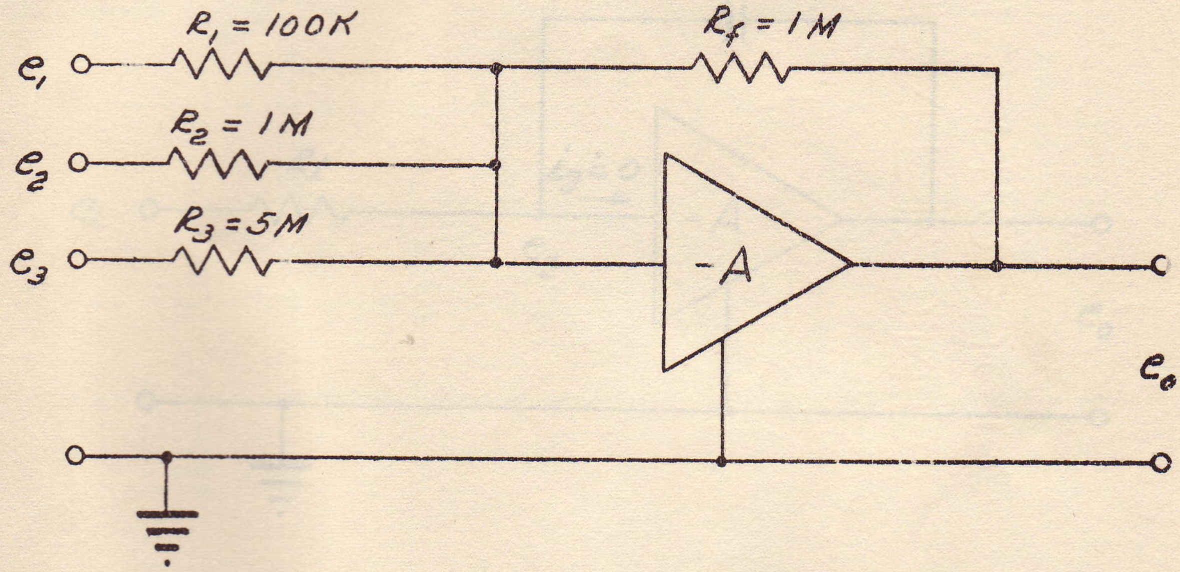
Figure 5: Operational Amplifier Illustrating Algebraic Summing of Arbitrary Input Voltages.



$$e_o = -e_i \frac{R_f}{R_i}$$

$$= -e_i$$

Figure [illegible] Operational Amplifier Illustrating Sign Changing.



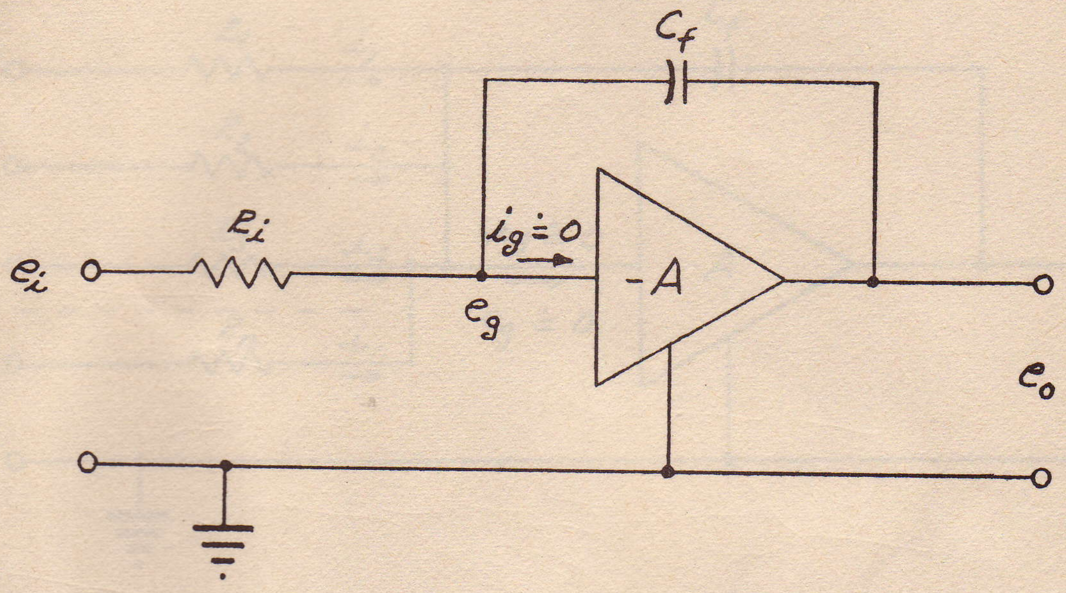
$$e_o = -\left(e_1\frac{R_f}{R_1} + e_2\frac{R_f}{R_2} + e_3\frac{R_f}{R_3}\right)$$

$$= -\left(10e_1 + e_2 + \frac{e_3}{5}\right)$$

IF $e_1 = 0$, $e_2 = -80$ VOLTS, $e_3 = 60$ VOLTS,

$$e_o = -(-80 + 12) = 68 \text{ VOLTS}$$

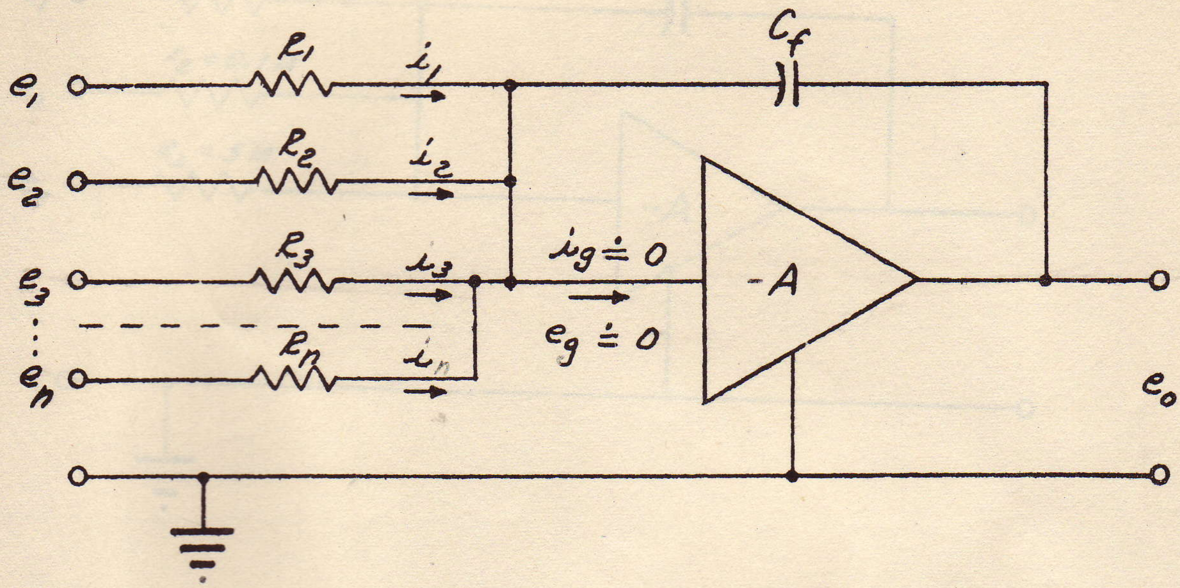
Figure 7: Operational Amplifier Illustrating Multiplication or Division by a Constant.



IF $i_g \doteq 0$ AND $e_g \doteq 0$,

$$e_o = -\frac{1}{R_i C_f}\int_0^t e_i \, dt + e_o\Big]_{t=0}$$

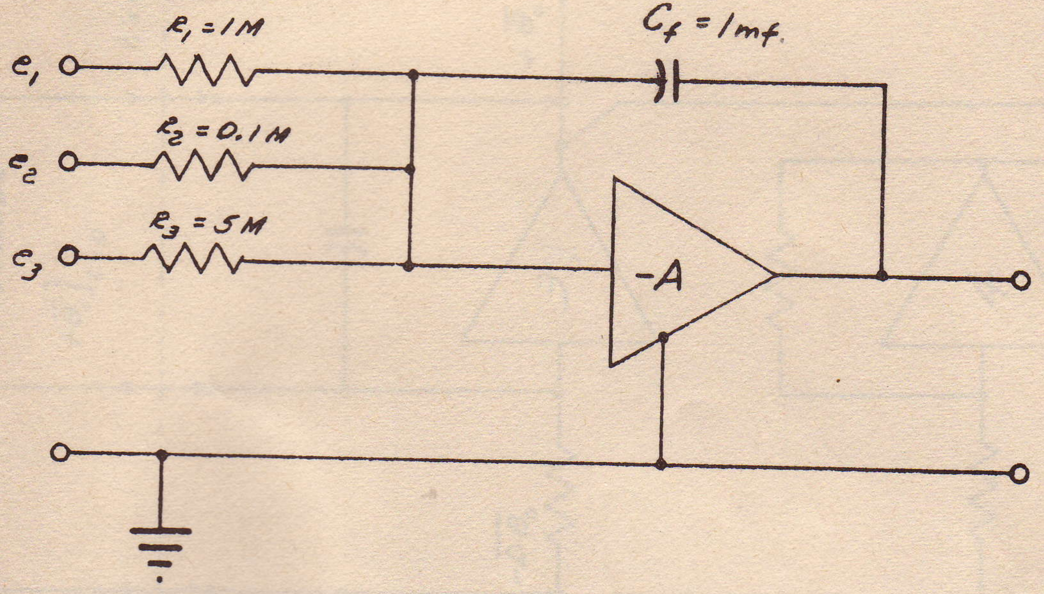
Figure 8: Operational Amplifier Illustrating Simple Integration.



IF $i_g \doteq 0$ AND $e_g \doteq 0$

$$e_o = -\frac{1}{C_f}\int_0^t \sum_1^n \frac{e_i}{R_i}\, dt + e_o]_{t=0}$$

Figure 9: Operational Amplifier Illustrating the Integration of an Algebraic Sum.



$$e_o = \frac{1}{C_f}\int_0^t \sum \frac{e_i}{R_i}\, dt + e_o\Big]_{t=0}$$

$$= -\frac{1}{1}\int_0^t \left(\frac{e_1}{1S} + \frac{e_2}{0.1S} + \frac{e_3}{5S}\right) dt + e_o\Big]_{t=0}$$

IF e_1 = 15 VOLTS, e_2 = −2 VOLTS, AND $e_3 = 10\frac{t}{S}$ VOLTS.

$$e_o = -\int_0^t \left(\frac{15V}{sec} - \frac{2V}{0.1sec} + \frac{10tV}{5sec^2}\right) dt$$

$$= -\int_0^t \left(\frac{-5}{sec} + \frac{2t}{sec^2}\right) dt$$

$$= \left(5\frac{t}{S} - \frac{t^2}{S^2}\right) \text{ VOLTS} + e_o\Big]_{t=0}$$

$$\cancel{= (t+5) \text{ VOLTS PER SECOND} + e_o\Big]_{t=0}}$$

Figure 10: Operational Amplifier Illustrating a Summing Integrator.

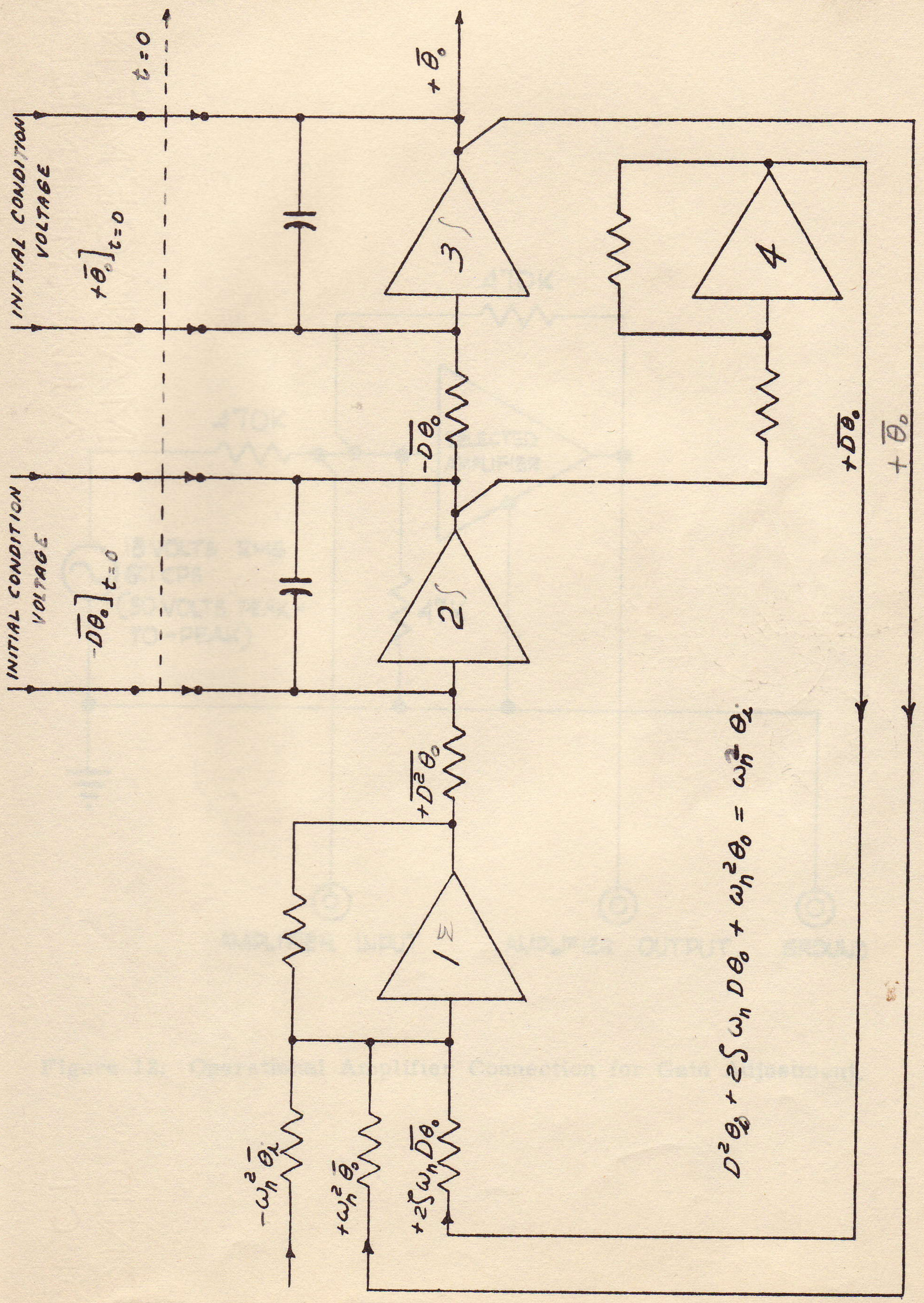


Figure 11: Computer Arrangement for Solution of General Second Order Differential Equation.

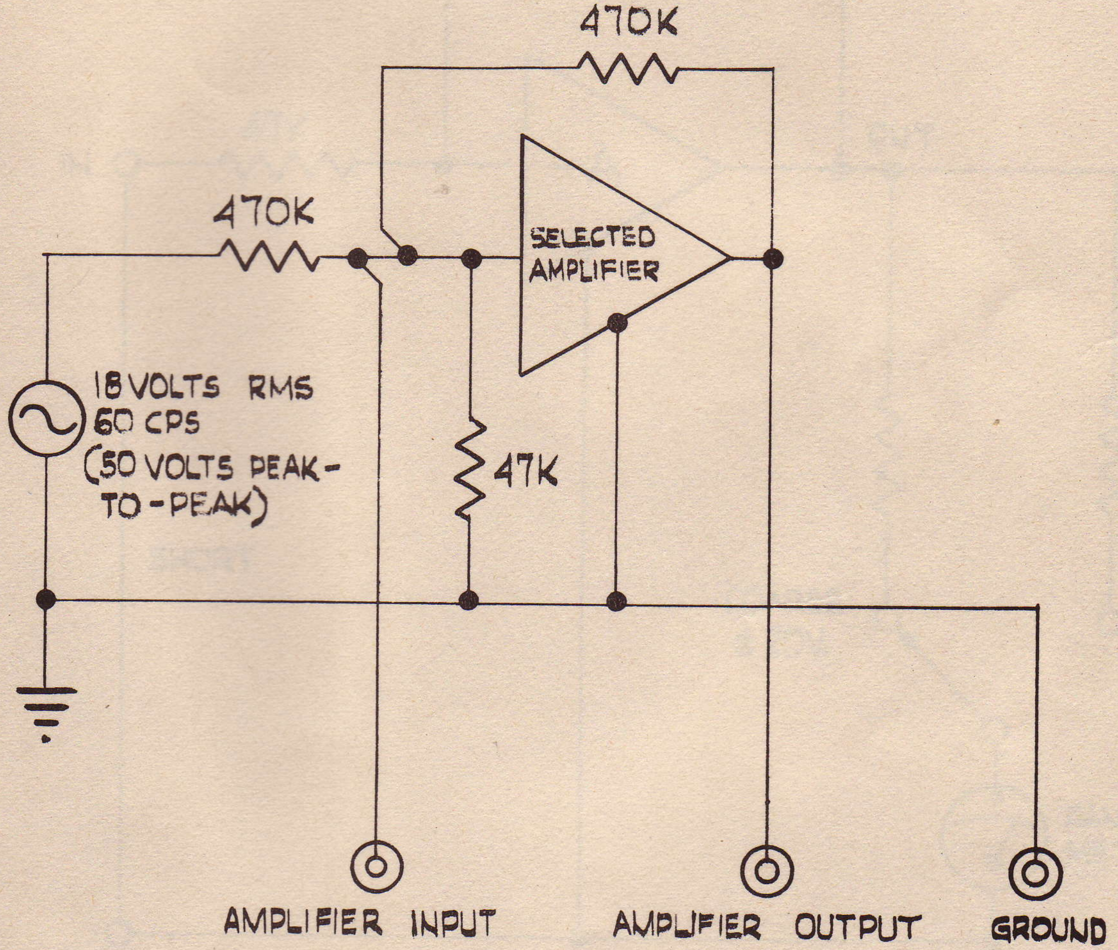


Figure 12: Operational Amplifier Connection for Gain Adjustment.

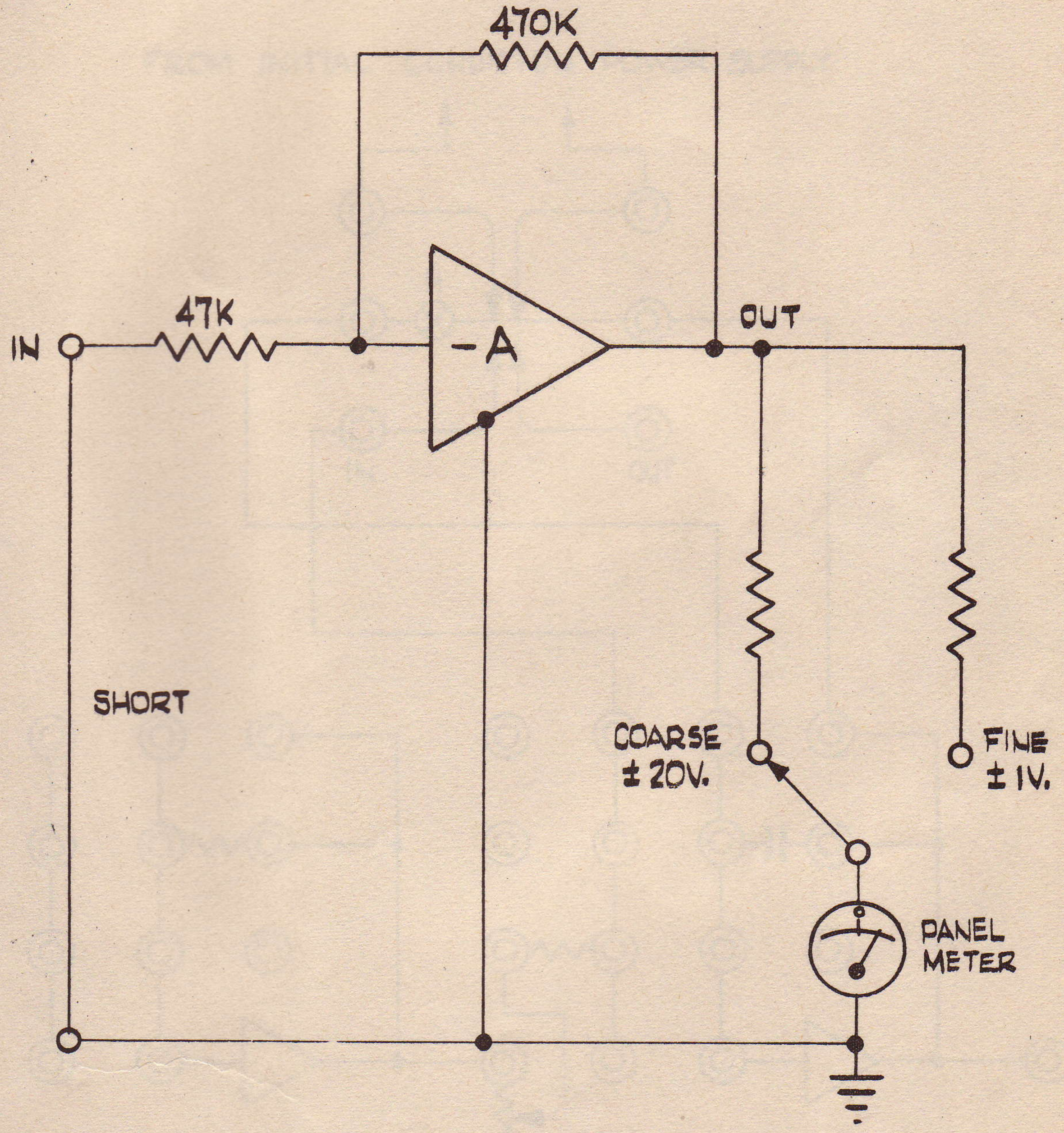


Figure 13: Operational Amplifier Connection for Balance Adjustment.

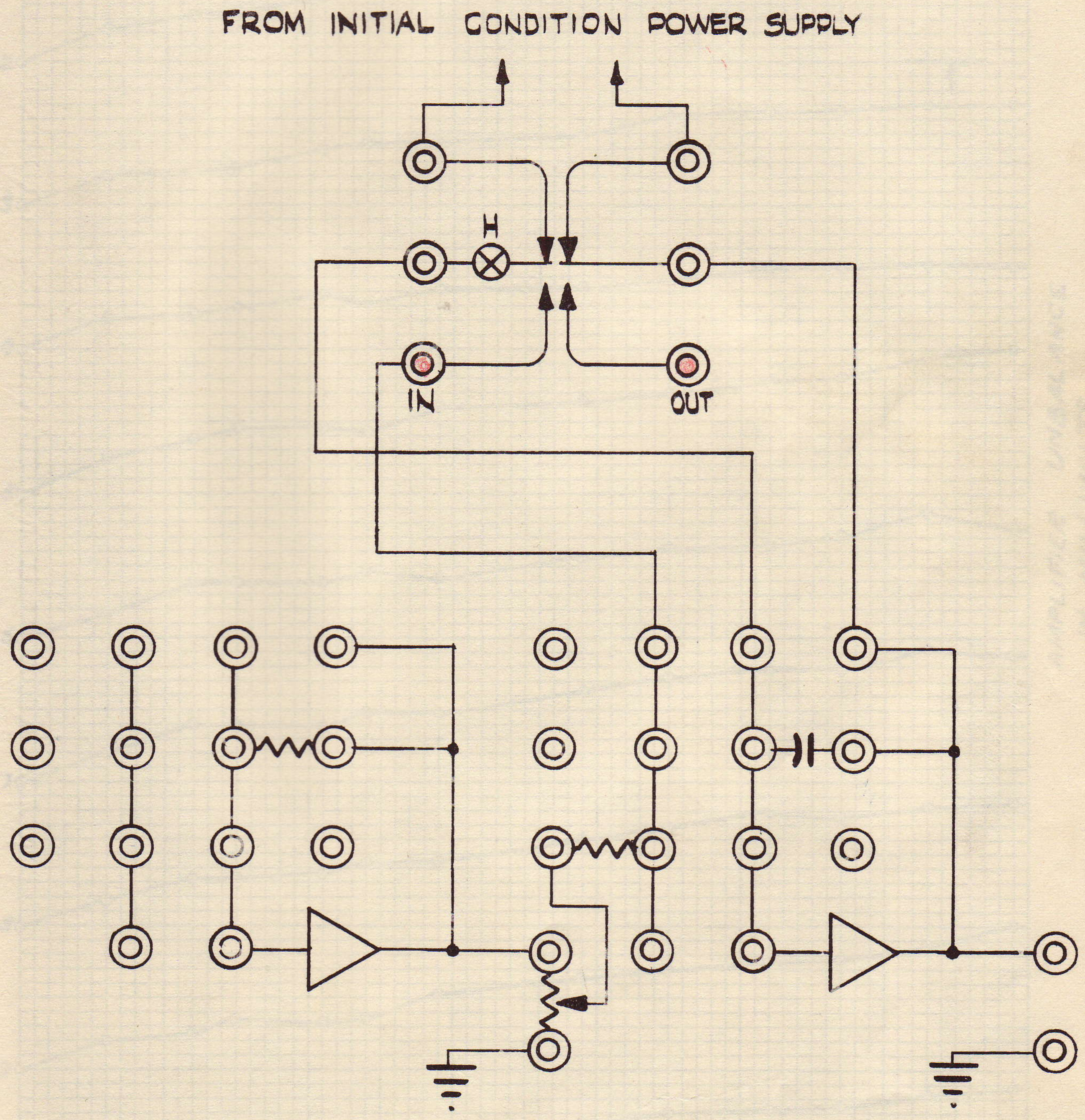


Figure 14: Problem Board Connections to One Integrator Involving COMPUTE-RESET and HOLD-OPERATE Relays.

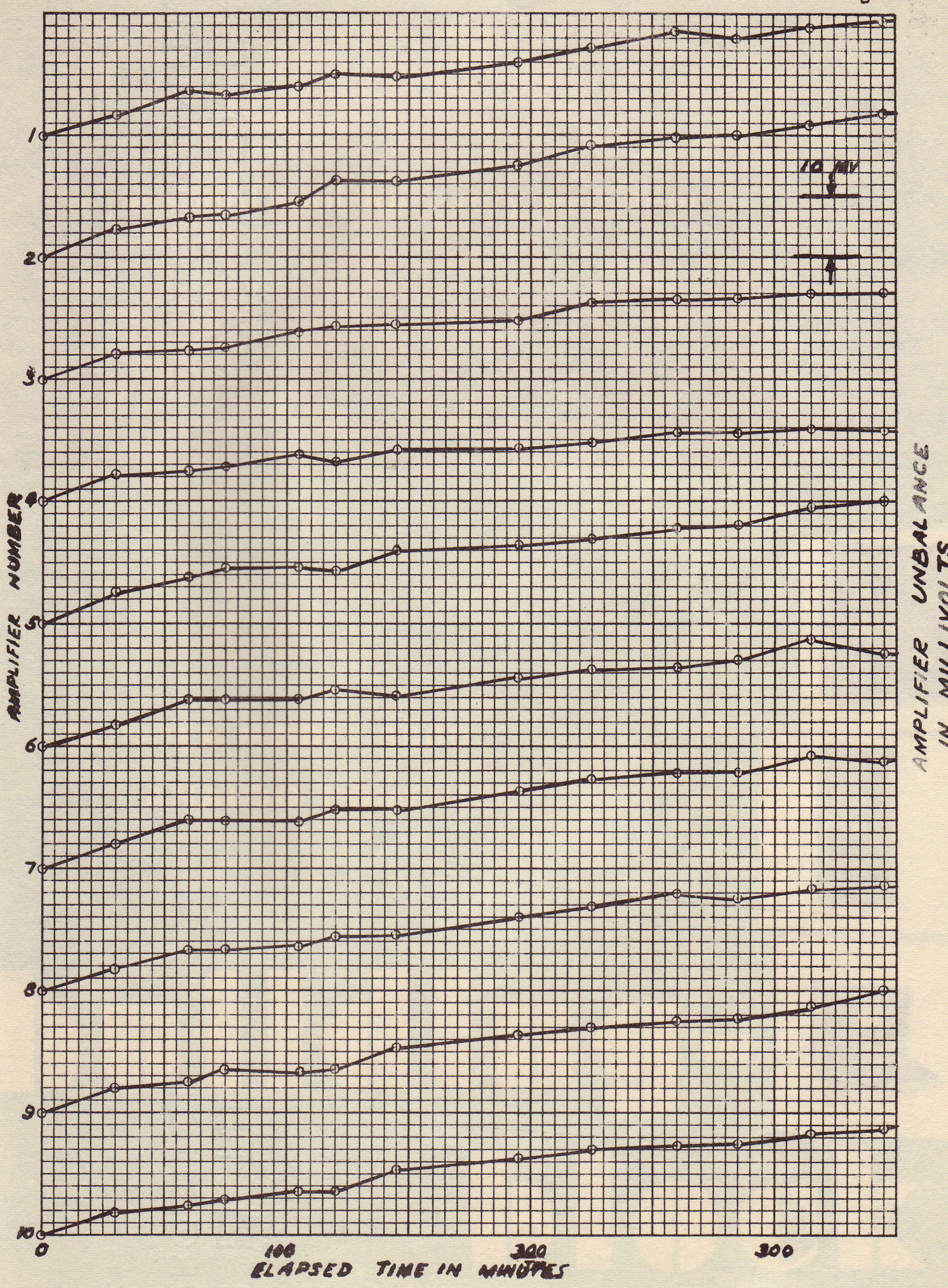
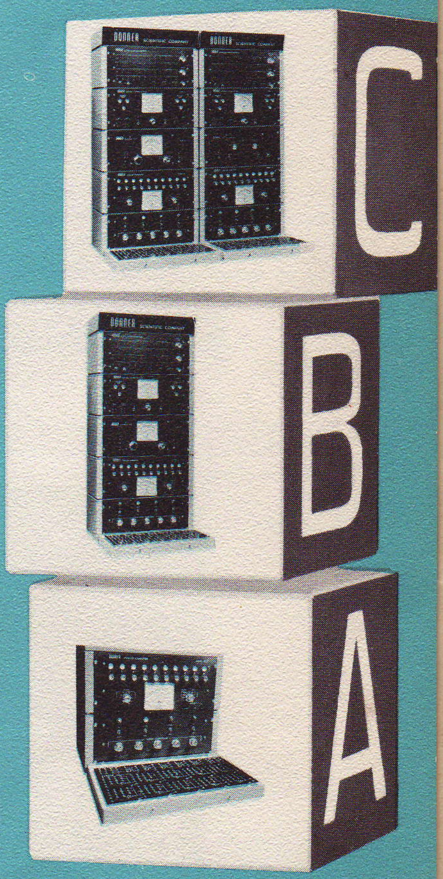


Figure 15: Averaged Drift of Operational Amplifiers

a personal tool for every engineer...

flexible computing facilities for product development, process simulation, research and instruction

DONNER MODEL 3000 ANALOG COMPUTER



building-block

SIMPLICITY

DONNER SCIENTIFIC COMPANY

A

DESK-TOP COMPUTER
(Shown with Model 3034 Problem Board)
Model 3000,
$1150.00

An engineering tool for product design, process simulation, research and development, and instruction. A complete DC analog computer, with self-contained power supplies and operating controls.

FEATURES

- 10 stable, high-gain operational amplifiers.
- 5 initial condition supplies, plus all computer power supplies.
- 2 floating diodes for limiting functions.
- Built-in controls, including Compute-Reset and Hold-Operate.
- Integral meter for set-up, readout and performance checking.
- Individual overload indicators and amplifier balance controls.

BASIC

The Model 3000 is the basic unit in a Donner building-block computing center. It is a complete analog computing facility — technically, a general-purpose DC electronic differential analyzer. With only a detachable problem board, a selection of plug-in components and a simple read-out device, it solves a wide variety of problems.

This small, desk-top unit for individual engineers or design groups is easily set up and operated. Quantitative results with accuracies within 1% are obtained, as well as qualitative indications. Detachable problem boards permit one engineer to use the main computing equipment, while others are constructing their own problems on separate boards for subsequent solution on the computer.

The Model 3000 is used for simulation of physical systems, which are expressed mathematically by differential equations or transfer functions. These are represented directly by computing components (resistors, capacitors and patch cords) plugged into the detachable problem board.

The computer operates in "real time" (duration of simulated problem same as interval being studied in the physical system), where desirable. Problems may be speeded up or slowed down, to facilitate examination and/or recording of the solution. Either one-time (manual control) or repetitive solution may be presented, the latter requiring an accessory (Model 3720 Cyclic Reset Generator) to control the COMPUTE-RESET function.

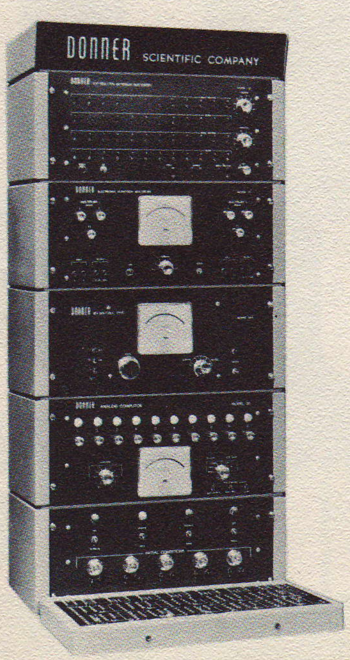
Problem solution may be interrupted at any instant, "freezing" it for precise measurement of its variables. The solution is then resumed by merely returning the HOLD-OPERATE switch to OPERATE. Output voltage of any operational amplifier, and thus the particular variable, is selected by a switch for presentation on a large panel meter. This meter has 3 full-scale sensitivities for high accuracy, plus provision for self-checking of computer performance.

Problem solutions are also available at output terminals on the computer and on the problem board. Recommended read-out devices are strip-chart recorders, X-Y plotters, digital voltmeters and oscilloscopes. The last is particularly convenient with repetitive solution presentation, where parameters may be changed rapidly to produce a desired pattern on the screen. An ideal physical system may thereby be synthesized; conversely, an existing system may be accurately analyzed.

EXPANDED

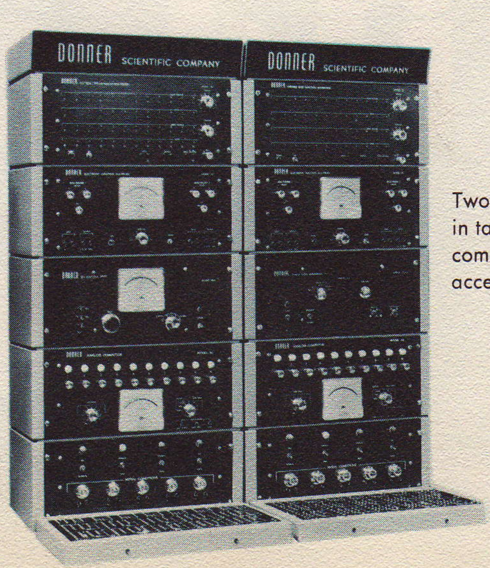
When problems to be solved exceed the capacity of the basic computer, two or even three Model 3000 Computers may readily be joined for simultaneous operation. Where non-linear differential equations and certain classes of transfer functions (involving multiplication, transport delay, etc.) are to be solved, accessories will be required. Chopper stabilization is provided by adding a single accessory. Donner modular design allows rapid addition or re-arrangement of these supplementary building-blocks.

B



Single desk-top computer with three accessories and cooling-fan top unit.

C

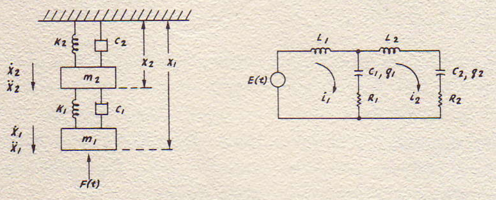


Two computers operated in tandem, with a large complement of accessories.

PROBLEM-HANDLING CAPACITY

The Model 3000 solves ordinary linear differential equations to the fifth order, also related transfer functions. This limitation is due to the availability of 10 operational amplifiers and 5 initial condition supplies; one amplifier is required for each integration (this integrator may be also a summer) or summation, and one initial condition supply is usually needed for each integrator. Where initial conditions need not be established, as in transfer functions and certain other simulations, a single Model 3000 can handle polynomials of the sixth or seventh order. The basic computer incorporates two floating diodes, for limiting functions. Non-linear problems may be solved with the addition of accessories, but the above considerations still apply.

The following problem, which utilizes the full capacity of this computer, involves two cross-coupled second order differential equations. This is a simulation of both a mechanical system and an electrical circuit, which are mathematically identical. The first consists of two masses, two springs and two viscous dampers; an initial forcing function or "kick" is applied to one mass, and both masses start with initial displacements and velocities. The second, a two-section RLC filter, has analogous provisions.



The equations of motion are:

$$F(t) = m_1 \ddot{x}_1 + C_1 (\dot{x}_1 - \dot{x}_2) + K_1 (x_1 - x_2)$$

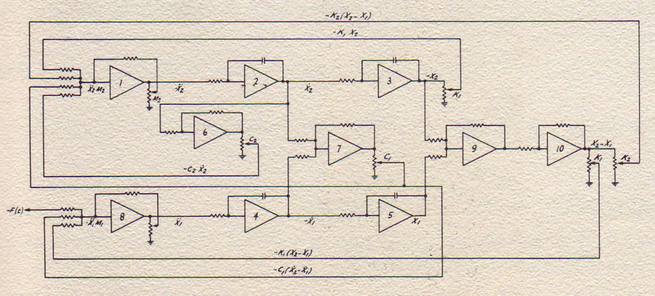
$$0 = m_2 \ddot{x}_2 - C_1 (\dot{x}_1 - \dot{x}_2) + C_2 \dot{x}_2 - K_2 (x_1 - x_2)$$

and

$$E(t) = L_1 \ddot{q}_1 + R_1 (\dot{q}_1 - \dot{q}_2) + \frac{1}{C_1} (q_1 - q_2)$$

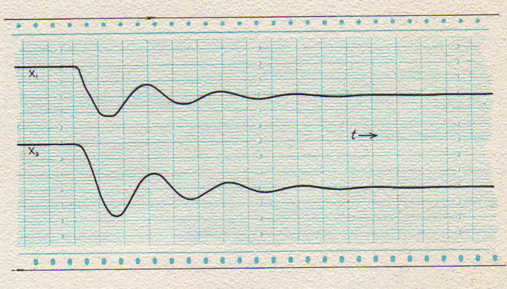
$$0 = L_2 \ddot{q}_2 - R_1 (\dot{q}_1 - \dot{q}_2) + R_2 \dot{q}_2 - \frac{1}{C_2} (q_1 - q_2)$$

Upon transposing the highest-order term to the left and dividing all terms by its coefficient, the equations can be directly represented in computer language. Integration of acceleration produces velocity, and integration of velocity yields displacement. Starting with the highest derivative, this procedure immediately develops into the following diagram.



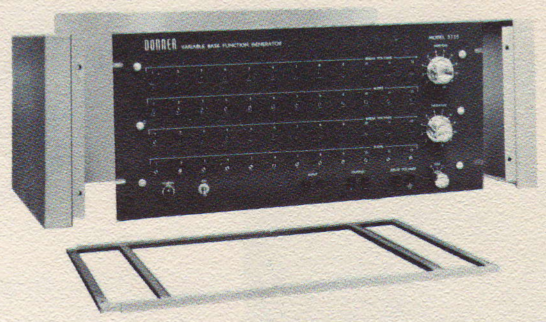
The problem, according to its diagram, is now constructed in an identical manner on the problem board. All variables are present as voltages changing in magnitude with time. Values of computing components are chosen for convenient solution times and desirable voltage amplitudes. Such "scaling" produces accurate answers, related in magnitude and time to the actual physical system by precise factors or multipliers. Velocities, et cetera, at "time zero" are set on the initial condition supplies and their values checked with the Model 5000 Null Voltmeter. This accessory is also essential for setting and reading true values (as loaded) established by the coefficient potentiometers.

If a very short solution time is used, problem answers may be viewed on an oscilloscope screen; cyclically repetitive presentation is very effective. With longer problem duration, a strip-chart recorder may be employed. The record below, made with a two-pen machine, shows the displacements of the two masses in the problem discussed.



The Model 3000 is capable of driving directly most oscilloscopes and strip-chart recorders. It will also operate X-Y plotters, high-speed oscillographs, digital voltmeters and various printing read-out devices. Many of these excellent auxiliaries can be mounted in standard Donner modules. Some other special equipment required for particular operations, such as servo resolvers, is also compatible electrically and mechanically.

MODULAR DESIGN



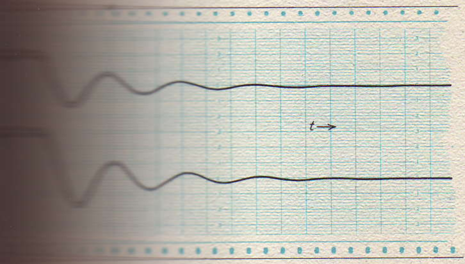
Versatility of the basic computer is increased by adding accessories in building-block manner. These are easily installed in cabinet modules, and all electrical connections are made by simply plugging in the cables furnished. For expanded capacity, two or three computers can be placed side-by-side and inter-connected for simultaneous operation.

The standard Donner cabinet module consists of two side-brackets, a spacer and a back plate. Simply bolt one to another to build up any desired assembly. The basic computer and all its accessories are furnished on standard 8¾x19 inch panels, usable in any cabinet module. Accessories are normally supplied with their own modules for "stacking" on an existing computer facility, but are also available in rack-mounting versions. All accessories (except Model 3760) are available with complete individual cabinets for use separately.

Desk-top computing facilities may be expanded to five modules per vertical bay. Larger bays, up to eight modules, must be floor-mounted; castered bases and shelf units (to support problem boards) are available for these. A cooling-fan top unit should be added to each modular assembly larger than the basic computer; i.e., three or more modules.

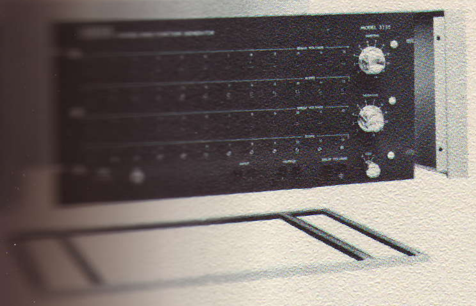
... the actual physical system by precise factors ... et cetera, at "time zero" are set on the ... and their values checked with the Model ... This accessory is also essential for setting and ... (as loaded) established by the coefficient poten-

... time is used, problem answers may be viewed ... screen; cyclically repetitive presentation is very ... problem duration, a strip-chart recorder may ... The record below, made with a two-pen machine, ... of the two masses in the problem discussed.



... capable of driving directly most oscilloscopes and ... It will also operate X-Y plotters, high-speed ... digital voltmeters and various printing read-out de- ... These excellent auxiliaries can be mounted in standard ... Some other special equipment required for particu- ... as servo resolvers, is also compatible electrically ...

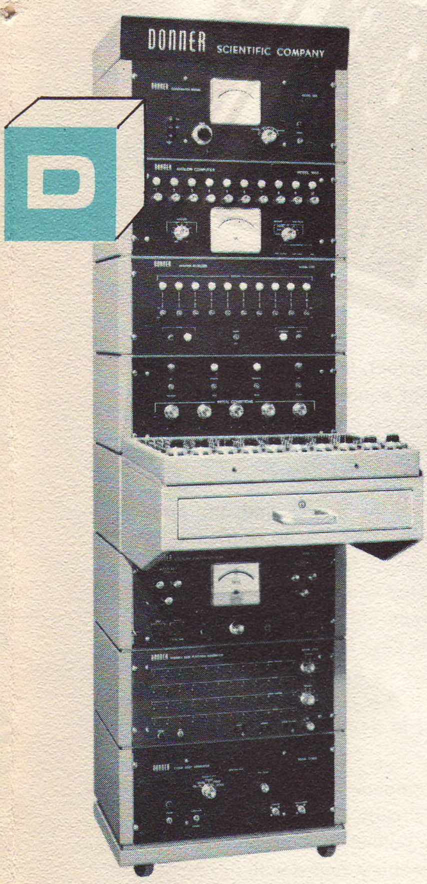
...ULAR DESIGN



... computer is increased by adding accessories in ... These are easily installed in cabinet modules, ... connections are made by simply plugging in the ... expanded capacity, two or three computers can ... and inter-connected for simultaneous opera-

... cabinet module consists of two side-brackets, a ... Simply bolt one to another to build up any ... The basic computer and all its accessories are fur- ... inch panels, usable in any cabinet module. ... supplied with their own modules for "stack- ... computer facility, but are also available in rack- ... accessories (except Model 3760) are available ... cabinets for use separately.

... facilities may be expanded to five modules per ... up to eight modules, must be floor-mounted; ... shelf units (to support problem boards) are avail- ... cooling-fan top unit should be added to each modu- ... than the basic computer; i.e., three or more



FLOOR MOUNTING BASE UNIT
Four swiveled casters permit easy moving. Contains replaceable fiber glass filter for air intake.
Model 3016, $60.00

ACCESSORIES

COOLING-FAN TOP UNIT
Required for each vertical bay of 3 or more modules, to insure proper cooling of equipment.
Model 3011, $90.00

NULL VOLTMETER
Essential for setting and measuring coefficient potentiometer values (loaded) and initial condition voltages.
Model 5000, $190.00

COMPUTER UPPER UNIT
Contains operational amplifiers and metering circuits. Must be placed immediately above Model 3760 (if used) or computer lower unit.

CHOPPER STABILIZER
Individual choppers stabilize 10 amplifiers above, essentially eliminating drift. Must be placed between computer units.
Model 3760, $1415.00

COMPUTER LOWER UNIT
Contains all power supplies, controls and problem board jacks. Must be lowest module for desk-top use, or be used with shelf unit below.

SHELF UNIT
Supports problem board and potentiometer strip. Drawer with lock provided for components.
Model 3021, $85.00

ELECTRONIC FUNCTION MULTIPLIER
2 separate channels accept independently varying inputs U, V, X and Y. Products UV and XY delivered.
Model 3730, $875.00

VARIABLE BASE FUNCTION GENERATOR
Closely approximates most single-valued functions by fitting 24 line-segments to curve desired.
Model 3750, $425.00

CYCLIC RESET GENERATOR
Resets and restarts computer after each 0.1- to 16-second computing interval (smoothly adjustable).
Model 3720, $200.00

Above accessories have integral power supplies, where required, with 115/230 volt, 50 or 60 cps input (specify power line voltage and frequency on order). Write for specific data sheets.

RECOMMENDED FACILITIES

Computing facilities below show growth of the desk-top computer to a complete computing center. Each successive complement of equipment provides more flexibility. Each has a recommended plug-in component selection to handle problems within its capacity.

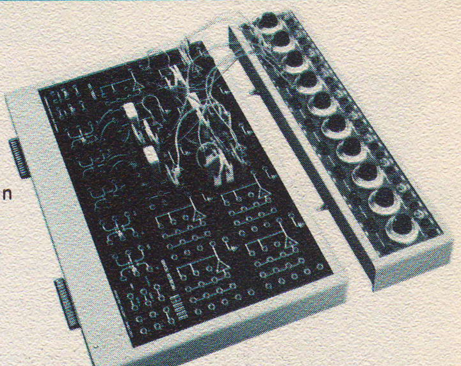
Donner Model	Facility "A" Desk-top	Facility "B" Desk-top	Facility "C" Desk-top	Facility "D" Floor-mount
3000	1	1	2	1
3011	1	1	2	1
3016	—	—	—	1
3021	—	—	—	1
3034	1	2	4	2
3071	1	—	—	—
3073	—	1	2	1
3720	—	—	1	1
3730	—	1	2	1
3750	—	1	2	1
5000	1	1	1	1
Components	"Budget"	"Versatile"	"Optimum II"	"Optimum I"
Price	$1835.60	$3,773.20	$7,422.00	$4,355.00

Individual chopper stabilization of operational amplifiers is provided by addition of Model 3760 (one per Model 3000) to any computing facility above.

Component selections range from a minimum to a fully flexible assortment:

"Budget" . . . $225.60 "Utility" . . . $394.00
"Versatile" . . $533.00 "Optimum I" . $770.00
"Optimum II" . $932.00 (Polystyrene capacitors)

DETACHABLE PROBLEM BOARD



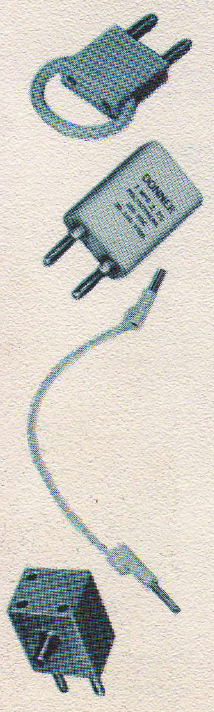
Model 3034, with jacks for plug-in components, $95.00 (shown with Model 3073 Potentiometer Strip). Model 3033, with solder posts, $85.00 (similar, not shown).

The Donner problem board has a "road map" layout, facilitating problem visualization and set-up. Individual terms in differential equations or transfer functions are constructed with patch cords, resistors, capacitors, and coefficient potentiometers. This step-by-step procedure develops a direct representation of the entire problem.

All amplifier inputs and outputs are available on the board, and any amplifier may be used as an integrator or a summer/inverter. There is no restriction on the number of inputs to any summing junction, and ample free-floating jack fields are included for convenience. All initial condition relay connections are made on the board. Jacks are provided for patching-in two separate Electronic Function Multiplier channels (one Model 3730) and one Variable Base Function Generator (Model 3750); connections to these jacks are brought out on the rear of the Model 3000 Computer for cabling to the respective accessories in a modular assembly. The two floating diodes in the Model 3000 are connected to designated jacks on the problem board.

The problem board mechanically engages the computer with two large multi-contact connectors, which also carry all electrical circuits. The board is attached by pushing it into place and is detached by simply pulling it. A problem set-up may be left undisturbed for future use by storing the problem board with its components in place.

PLUG-IN COMPONENTS



PRECISION RESISTORS

1% tolerance, deposited carbon, molded in rubber with convenient handles. Through-connections allow "stacking" for easy problem set-up. Values 0.1, 0.2, 0.5, 1, 2, 5 and 10 megohms — each marked and colored distinctively (1% and 0.1% wire-wound resistors also available).

Series 30-101, $2.80 each

INTEGRATING CAPACITORS

Mylar dielectric, 1% tolerance recommended for general use. Polystyrene dielectric, 1% tolerance (0.1% also available) provided for critical applications.

Type	0.01 μfd	0.1 μfd	1 μfd
Poly, Series 30-110	$8.40	$9.80	$28.00
Mylar, Series 30-111	6.50	7.50	16.00

PATCH CORDS

Four color-identified lengths (4, 8, 12 and 24 inches) speed problem construction. Through-connections permit "stacking."

Series 30-120, $1.60 each

COEFFICIENT POTENTIOMETER

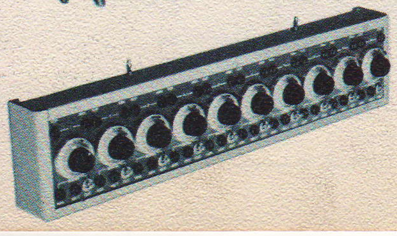
0.1 megohm composition plug-in unit, molded with through-connections.

Model 3061, $7.20 each

POTENTIOMETER STRIPS

Ten single-turn, 0.1 megohm composition pots in a narrow cabinet which attaches to problem boards; second and third strips may be added. Jacks and switching circuits provided for measuring actual (loaded) values with Model 5000 Null voltmeter.

Model 3071, $85.00



Similar strip, but with ten 10-turn precision wire-wound pots, 0.1 megohm and 0.5% linearity, plus ten dual-indicating dials. Model 3073, $320.00

SPECIFICATIONS

MAIN POWER SUPPLIES

Positive and negative DC supplies, also amplifie heater supply, closely regulated for stability.

INITIAL CONDITION SUPPLIES

5 regulated, floating sources of 0 to 100 volts (smo either polarity) at 5 milliamperes maximum.

OPERATIONAL RELAYS

Initial condition relays, actuated by COMPUTE-RES connected on problem board to remove or set in in system disturbances (step functions, etc.).

Hold relays, actuated by HOLD-OPERATE switch, c nected to arrest progress of problem solution until s

METERING CIRCUITS

$4\frac{1}{2}$ inch square, zero-center meter with 2, 20 and sensitivities reads outputs of selected amplifiers. Co ance-check positions provided, also switch position ment with oscilloscope.

INPUT POWER REQUIREMENT

105-125 volts, 60 cps, 350 watts; 230 volts, 50 cp order (specify).

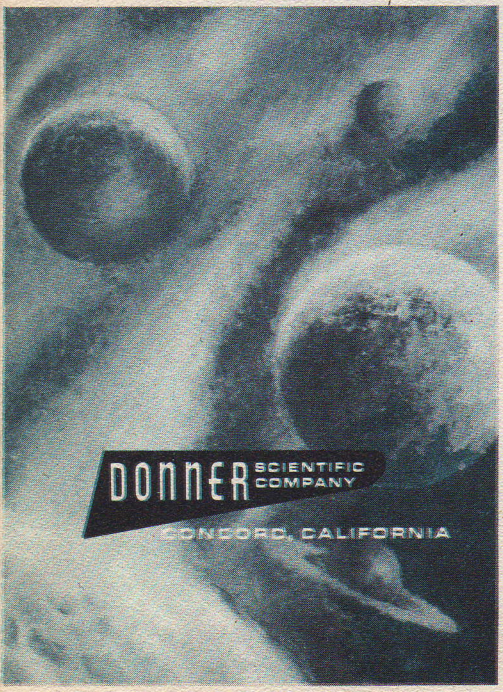
DIMENSIONS

Basic computer cabinet 21 wide x 19 high x 15 inc 100 pounds net, 115 pounds shipping (domestic pacl

Problem board 21 wide x 2 high x 14 inches deep. net, 15 pounds shipping (domestic packing).

PRICE

Model 3000 Analog Computer, $1150.00. All pric Factory (Concord, California). Prices and technical ject to change without notice.



ANALOG COMPUTERS • TE

SPECIFICATIONS

MAIN POWER SUPPLIES

Positive and negative DC supplies, also amplifier input pentode heater supply, closely regulated for stability.

INITIAL CONDITION SUPPLIES

5 regulated, floating sources of 0 to 100 volts (smoothly adjustable, either polarity) at 5 milliamperes maximum.

OPERATIONAL RELAYS

Initial condition relays, actuated by COMPUTE-RESET switch, can be connected on problem board to remove or set in initial conditions or system disturbances (step functions, etc.).

Hold relays, actuated by HOLD-OPERATE switch, are internally connected to arrest progress of problem solution until switch is reset.

METERING CIRCUITS

4½ inch square, zero-center meter with 2, 20 and 100 volt full-scale sensitivities reads outputs of selected amplifiers. Coarse and fine balance-check positions provided, also switch position for gain measurement with oscilloscope.

INPUT POWER REQUIREMENT

105-125 volts, 60 cps, 350 watts; 230 volts, 50 cps version, special order (specify).

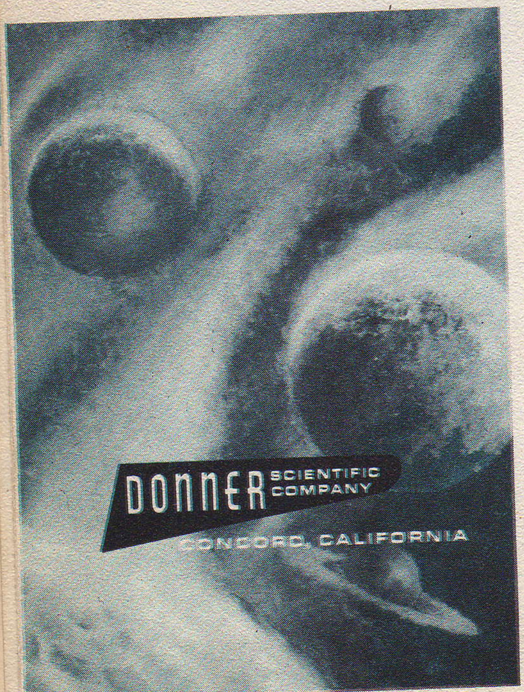
DIMENSIONS

Basic computer cabinet 21 wide x 19 high x 15 inches deep. Weight 100 pounds net, 115 pounds shipping (domestic packing).

Problem board 21 wide x 2 high x 14 inches deep. Weight 12 pounds net, 15 pounds shipping (domestic packing).

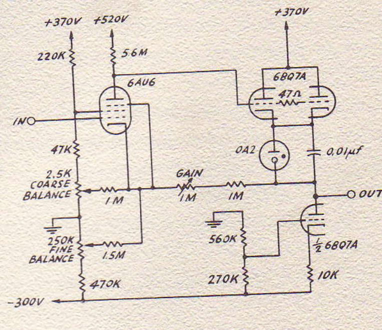
PRICE

Model 3000 Analog Computer, $1150.00. All prices domestic, FOB Factory (Concord, California). Prices and technical specifications subject to change without notice.



OPERATIONAL AMPLIFIERS

Each of the 10 identical amplifiers uses a single stage of amplification employing a pentode direct-coupled to a series-balanced cathode follower. This unique design (U.S. Patent 2,581,456 by Dr. I. H. Swift formerly of U.S.N.O.T.S.) provides a single time-constant, thereby minimizing phase shift and permitting use of very high gain with freedom from oscillation. Proper operation is also insured to much higher frequencies than with other circuits involving multiple stages and corrective networks.



Model 3000 Operational Amplifier

The basic open-loop gain of this single-stage amplifier is greater th 1000 over the full ± 100 volt output range. This is regenerativ increased to 10,000 (minimum, with aged tubes) over the ±100 range, and exceeds 50,000 for outputs within ±50 volts. The unus ly high gain reduces computer amplifier error (imperfect result to non-infinite gain) to an insignificant value.

Each amplifier is normally connected with very large negative f back around its single high-gain stage. Exceptional stability and i pendence of supply voltage fluctuations result from this combin of extremely high gain and negative feedback. Thus, precise inte tion (the most critical operation in computer work) is achievable long periods. Where necessary for near-total elimination of drift, vidual chopper stabilization is provided by addition of the Model accessory.

UNSTABILIZED AMPLIFIERS (MODEL 3000 ALONE)

GAIN: 10,000 minimum over full ±100 volt range; 50,000 minimum within ±5 range.

PHASE SHIFT: 1° at 10 kc, as installed with problem board and connected as gain inverter.

LONG-TERM DRIFT: Less than 4 millivolts per hour, referred to summing juncti unity-gain inverter.

SHORT-TERM RANDOM DRIFT: Less than 2 millivolts, under normal operating tions.

GRID CURRENT: Less than 10^{-9} ampere (10^{-10} ampere typical) at summing junct problem board.

HUM AND NOISE LEVEL: 1 millivolt rms or less, down at least 90 db from full value.

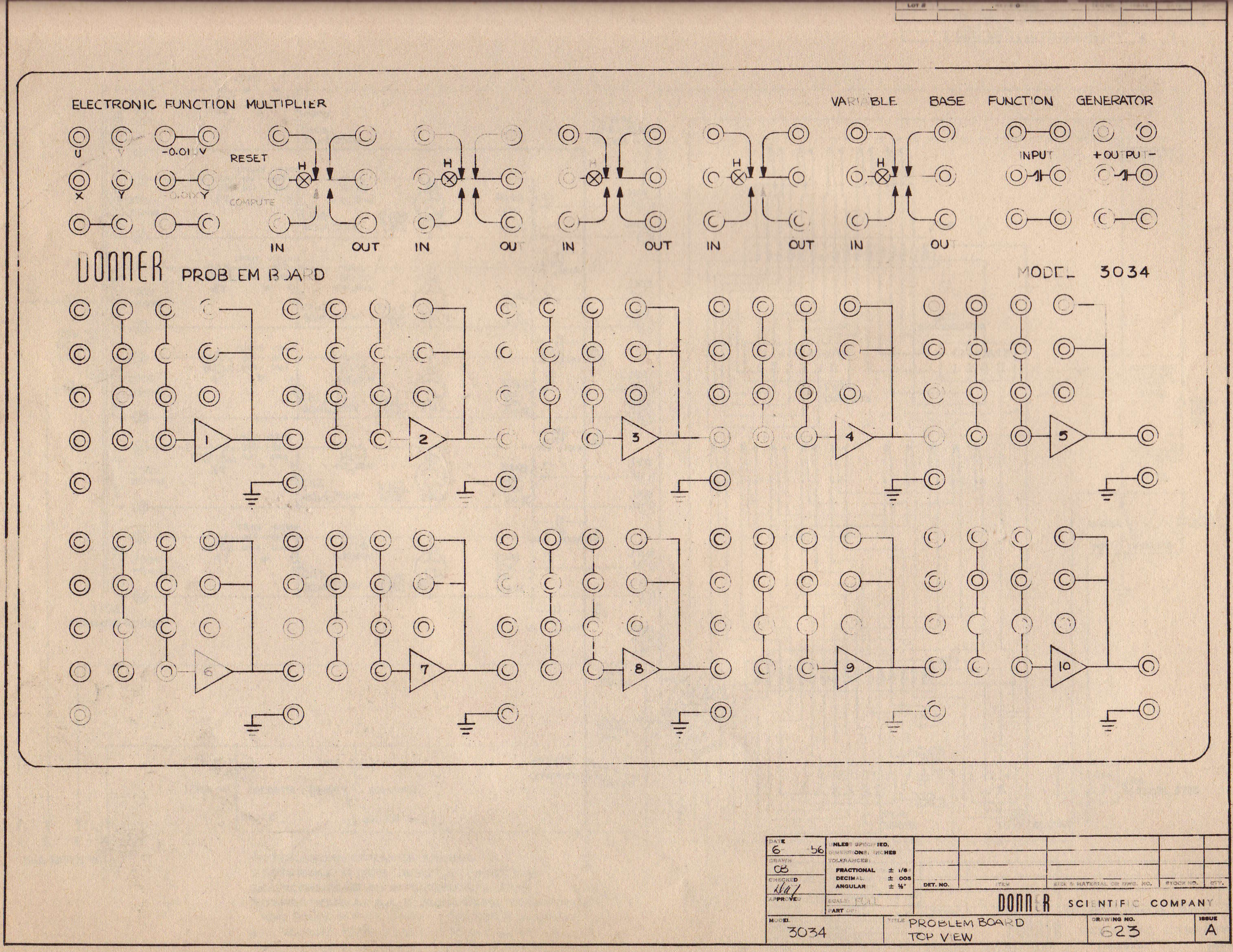
OUTPUT: 5 milliamperes over ±100 volt range, with individual overload indi

STABILIZED AMPLIFIERS (MODEL 3760 ADDED)

GAIN: 10^7 minimum at zero frequency (DC) over full ±100 volt range. Abo frequency, same as when unstabilized.

DRIFT: Less than 0.1 millivolt total excursion, referred to summing junction, a gain inverter.

(all other characteristics unchanged)


ELECTRONIC FUNCTION MULTIPLIER
U
X
-0.01 V
0.01XY
RESET
COMPUTE
H
IN
OUT
VARIABLE BASE FUNCTION GENERATOR
INPUT
+OUTPUT-
DONNER PROBLEM BOARD
MODEL 3034
1
2
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4
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6
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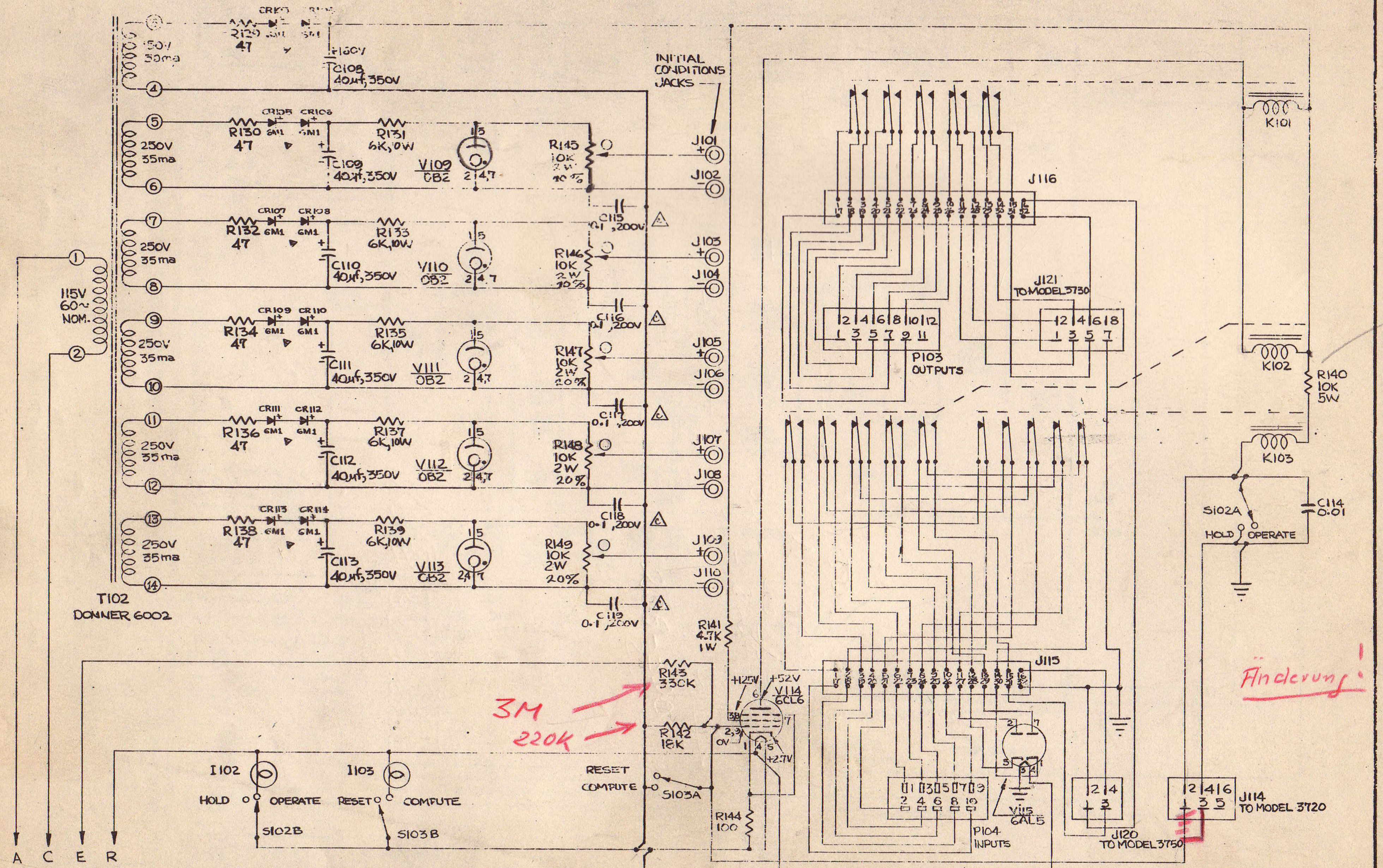
8
9
10
DATE 6 56
DRAWN CB
CHECKED
APPROVED
UNLESS SPECIFIED, DIMENSIONS: INCHES
TOLERANCES:
FRACTIONAL ± 1/64
DECIMAL ± .005
ANGULAR ± ½°
SCALE
PART
DET. NO.
ITEM
SIZE & MATERIAL OR DWG. NO.
STOCK NO.
QTY.
DONNER SCIENTIFIC COMPANY
MODEL 3034
TITLE PROBLEM BOARD TOP VIEW
DRAWING NO. 623
ISSUE A

evtl. auf 5,6 kΩ (2W) erniedrigen

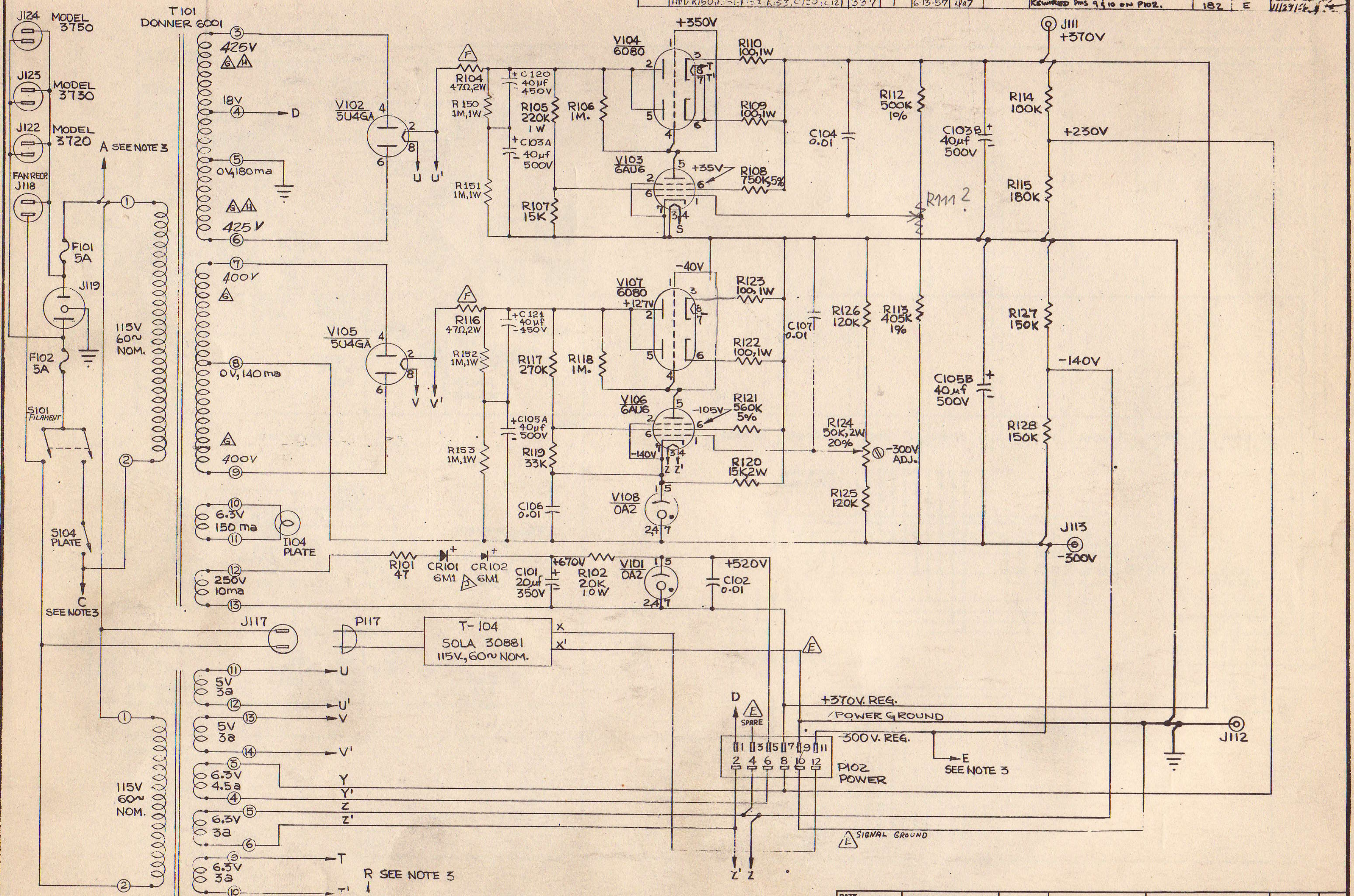


NOTES: UNLESS OTHERWISE SPECIFIED.
1. RESISTANCE IN OHMS. RESISTORS ½ WATT, 10%.
2. CAPACITANCE VALUES IN MICROFARADS, 500V.
3. CONNECTIONS AT A, C, E, AND R REFER TO DRAWING NO 824, POWER SUPPLY CHASSIS; SECTION A SCHEMATIC.
4. ALL VOLTAGES MEASURED WITH A 20,000 OHMS-PER-VOLT VOLTMETER WITH S103 IN COMPUTE POSITION.

DATE	5-31-56
DRAWN	BUTTERFIELD
CHECKED	
APPROVED	
MODEL	300C
UNLESS SPECIFIED, DIMENSIONS: INCHES. TOLERANCES: FRACTIONAL ± 1/64; DECIMAL ± .005; ANGULAR ± ½°	
SCALE:	
PART OF:	
TITLE	SCHEMATIC-POWER SUPPLY CHASSIS:-SECTION B
DRAWING NO.	825
	E

DONNER SCIENTIFIC COMPANY

V114 Gitter zu Kath. Kondensator



NOTES: UNLESS OTHERWISE SPECIFIED.

1. RESISTANCE IN OHMS. RESISTORS ½ WATT, 10%.
2. CAPACITANCE VALUES IN MICROFARADS, 500 VOLTS.
3. CONNECTIONS AT A, C, E & R REFER TO DWG. 825, POWER SUPPLY CHASSIS: SECTION B.
4. ALL VOLTAGES MEASURED WITH A 20,000 OHMS-PER-VOLT VOLTMETER, WITH S103 IN COMPUTE POSITION.

DATE	5-28-56
DRAWN	BUTTERFIELD
CHECKED	Anderson
APPROVED	
MODEL	3000
UNLESS SPECIFIED, DIMENSIONS: INCHES	
TOLERANCES: FRACTIONAL	± 1/64
DECIMAL	± .005
ANGULAR	± ½°
SCALE:	
PART OF:	

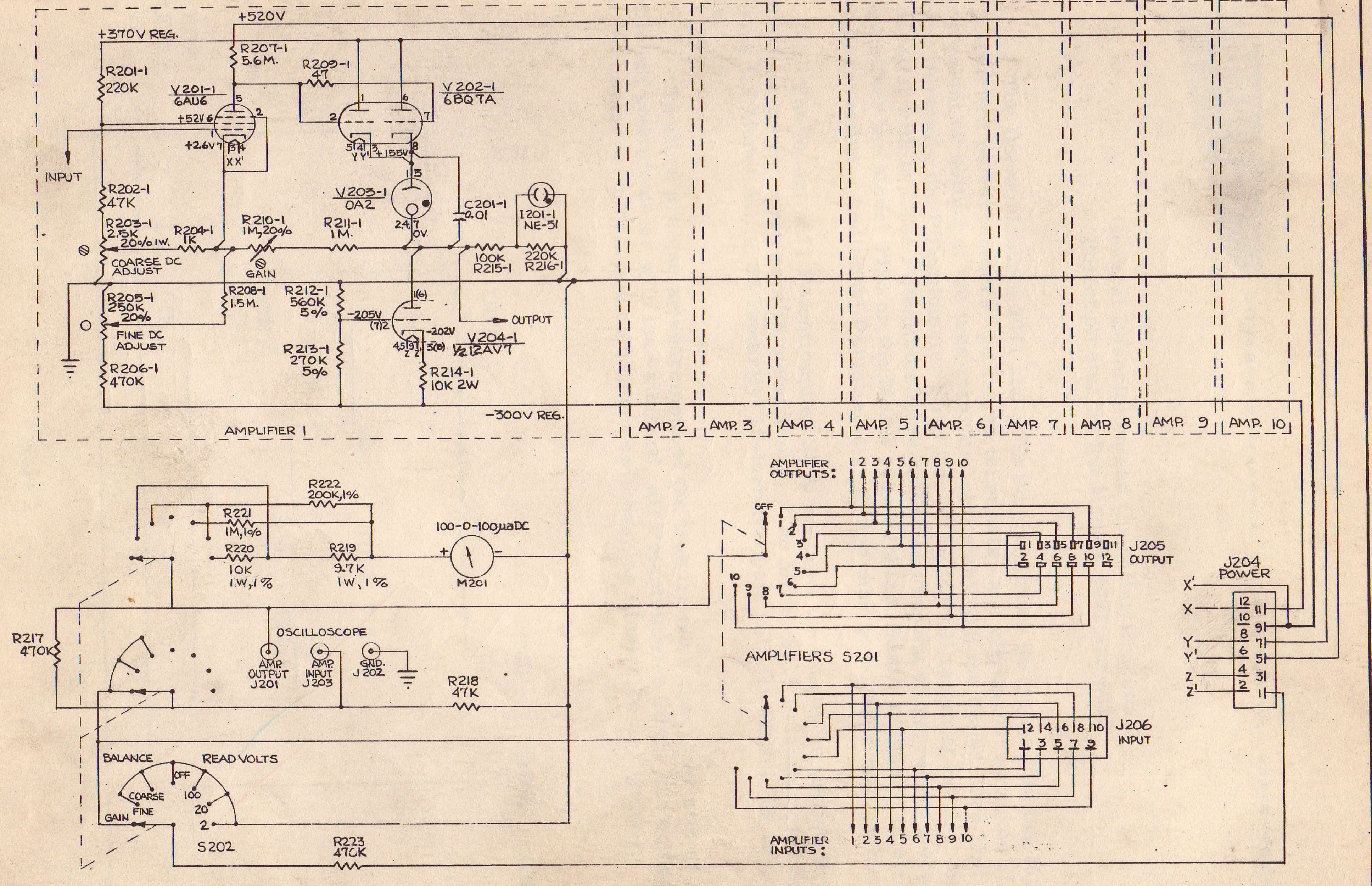
DET. NO.	ITEM	SIZE & MATERIAL OR DWG. NO.	STOCK NO.	QTY.

DONNER SCIENTIFIC COMPANY

TITLE SCHEMATIC – POWER SUPPLY CHASSIS : SECTION A

DRAWING NO. 824

ISSUE J



NOTES: UNLESS OTHERWISE SPECIFIED—
1. RESISTANCE IN OHMS RESISTORS ½ WATT 10%
2. CAPACITANCE VALUES IN MICROFARADS 500 VOLTS.
3. ENCLOSED SECTIONS OF ALL TEN AMPLIFIERS ARE IDENTICAL.
4. ALL VOLTAGES MEASURED WITH A 20,000 OHMS-PER-VOLT VOLTMETER, WITH S103 IN COMPUTE POSITION.

DATE 5-22-56	UNLESS SPECIFIED, DIMENSIONS: INCHES TOLERANCES: FRACTIONAL ± 1/64 DECIMAL ± .005 ANGULAR ± ½°	DET. NO.	ITEM	SIZE & MATERIAL OR DWG. NO.	STOCK NO.	QTY.
DRAWN DB						
CHECKED						
APPROVED 8/9/56	SCALE:	DONNER SCIENTIFIC COMPANY				
MODEL 3000	PART OF:	TITLE SCHEMATIC — AMPLIFIERS AND SWITCHING CIRCUITS		DRAWING NO. 823		ISSUE C

General Description and Operating Procedure
Potentiometer Strips Models 3071 and 3073

The Donner Models 3071 and 3073 Potentiometer Strips contain ten 100,000 ohm coefficient potentiometers, jack-type terminals, and disconnect switches allowing measurement or setting of the true transfer coefficient with the Model 5000 Null Voltmeter. Normally the Potentiometer Strip lies along the full length of the problem board and parallel with it. The Potentiometer Strip has two banana plugs, which mechanically engage either the Model 3033 or the Model 3034 Problem Board and make an electrical ground connection. Additional Potentiometer Strips may be engaged with each other.

The Model 3071 Potentiometer Strip contains ten single-turn Allen Bradley composition potentiometers with metal knobs. The Model 3073 Potentiometer Strip contains ten Model AZ (0.5% linearity) 10-turn Helipots with ten Model RB 10-turn Duodials.

To allow precise measurement of the true transfer characteristic of the coefficient potentiometer with load attached, all Potentiometer Strips are equipped with Null Voltmeter terminals and disconnect switches, as illustrated in Figure 1.

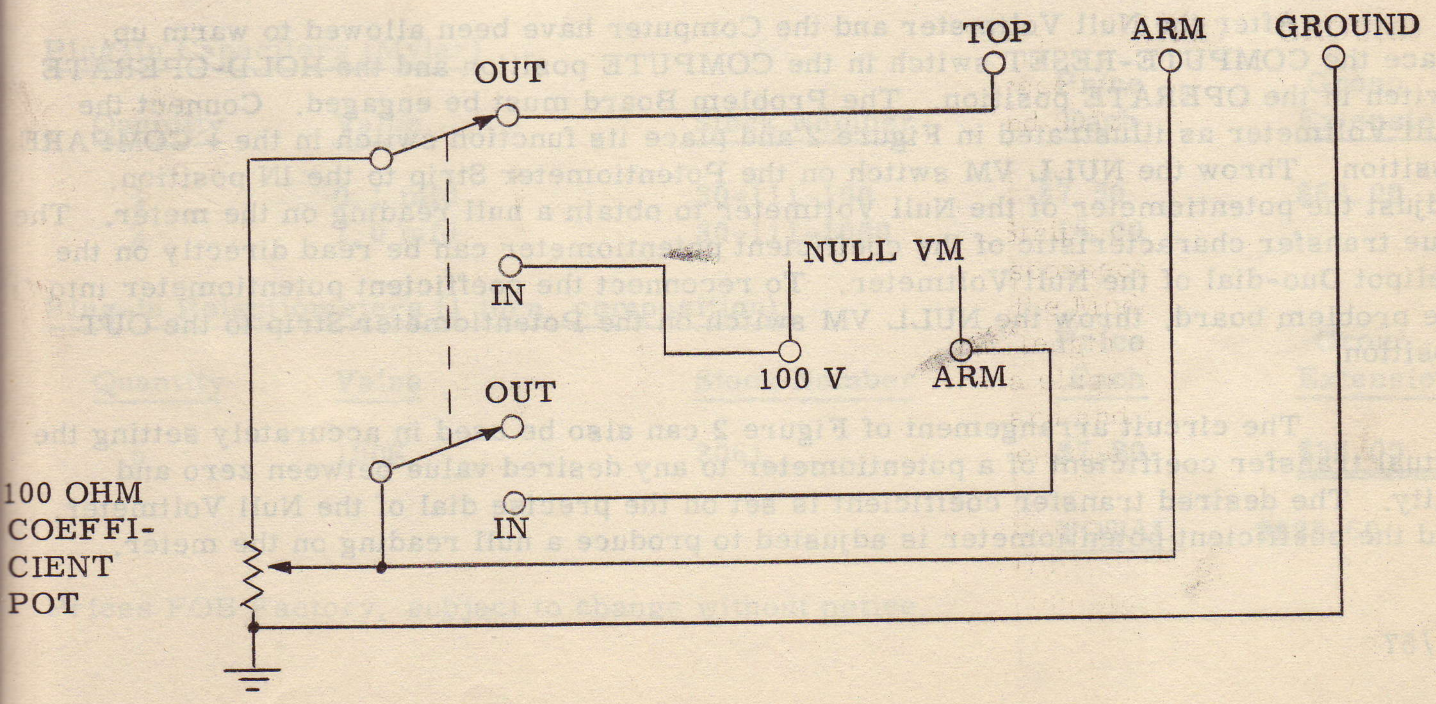


Figure 1

Figure 2 shows a coefficient potentiometer conventionally connected between the output of Amplifier A and the input of Amplifier B. The actual transfer coefficient established by the potentiometer is usually not the simple resistance ratio (potentiome dial reading); it is partially determined by the loading of the input resistor to Amplifie (connected between the potentiometer arm and the virtual ground at the amplifier input)

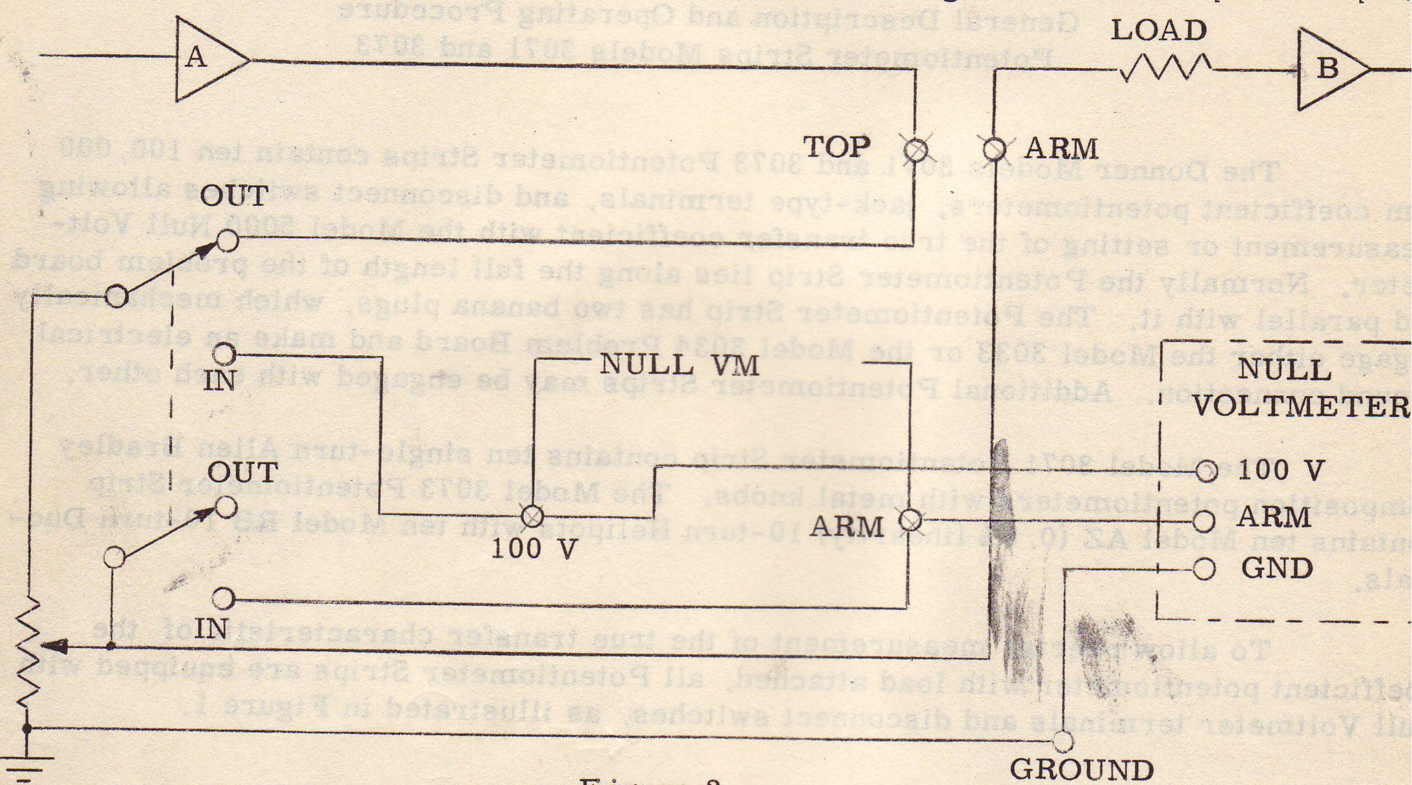


Figure 2

After the Null Voltmeter and the Computer have been allowed to warm up, place the COMPUTE-RESET switch in the COMPUTE position and the HOLD-OPERATE switch in the OPERATE position. The Problem Board must be engaged. Connect the Null Voltmeter as illustrated in Figure 2 and place its function switch in the + COMPAR position. Throw the NULL VM switch on the Potentiometer Strip to the IN position. Adjust the potentiometer of the Null Voltmeter to obtain a null reading on the meter. T true transfer characteristic of the coefficient potentiometer can be read directly on the Helipot Duo-dial of the Null Voltmeter. To reconnect the coefficient potentiometer into the problem board, throw the NULL VM switch on the Potentiometer Strip to the OUT position.

The circuit arrangement of Figure 2 can also be used in accurately setting th actual transfer coefficient of a potentiometer to any desired value between zero and unity. The desired transfer coefficient is set on the precise dial of the Null Voltmeter, and the coefficient potentiometer is adjusted to produce a null reading on the meter.

DONNER SCIENTIFIC COMPANY CONCORD, CALIFORNIA • MULBERRY 2-6161 • CABLE "DONNER"

RECOMMENDED COMPUTING COMPONENT ASSORTMENTS FOR MODEL 3000 ANALOG COMPUTER

BUDGET Component Selection

Applications: Many illustrative simulations and simpler engineering problems on a single Model 3034 Problem Board.

Patch Cords

Quantity	Length	Stock Number	Price Each	Group Extension
16	4"	30-120-4	$1.60	$57.60
8	8"	30-120-8	"	
8	12"	30-120-12	"	
4	24"	30-120-24	"	

Plug-in Resistors (1% deposited carbon)

Quantity	Value	Stock Number	Price Each	Group Extension
5	0.2 meg	30-101-20	$2.80	$70.00
5	0.5 meg	30-101-50	"	
5	1.0 meg	30-101-100	"	
5	2.0 meg	30-101-200	"	
5	10.0 meg	30-101-1000	"	

Plug-in Capacitors (Mylar)

Quantity	Value	Stock Number	Price Each	Group Extension
4	0.1 mfd	30-111-100	$7.50	$62.00
2	1.0 mfd	30-111-1000	16.00	

Plug-in Potentiometers (1 turn, composition)

Quantity	Value	Stock Number	Price Each	Group Extension
5	100K	3061	$7.20	$36.00
			TOTAL	$225.60

Prices FOB Factory, subject to change without notice.

3/24/58

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RECOMMENDED COMPUTING COMPONENT ASSORTMENTS FOR MODEL 3000 ANALOG COMPUTER

UTILITY Component Selection

Applications: Good choice of components for scaling and setup of complicated problem on single problem board, or illustrative problems on two boards.

Patch Cords

Quantity	Length	Stock Number	Price Each	Group Extension
20	4"	30-120-4	$ 1.60	$ 96.00
15	8"	30-120-8	"	
15	12"	30-120-12	"	
10	24"	30-120-24	"	

Plug-in Resistors (1%, deposited carbon)

Quantity	Value	Stock Number	Price Each	Group Extension
5	0.1 meg	30-101-10	$ 2.80	$ 112.00
5	0.2 meg	30-101-20	"	
5	0.5 meg	30-101-50	"	
10	1.0 meg	30-101-100	"	
5	2.0 meg	30-101-200	"	
5	5.0 meg	30-101-500	"	
5	10.0 meg	30-101-1000	"	

Plug-in Capacitors (Mylar)

Quantity	Value	Stock Number	Price Each	Group Extension
5	0.01 mfd	30-111-010	$ 6.50	$ 150.00
5	0.1 mfd	30-111-100	7.50	
5	1.0 mfd	30-111-1000	16.00	

Plug-in Potentiometers (1-turn composition)

Quantity	Value	Stock Number	Price Each	Group Extension
5	100 K	3061	$ 7.20	$ 36.00
			TOTAL	$ 394.00

Prices FOB Factory, subject to change without notice.

January 1957

DONNER SCIENTIFIC COMPANY   CONCORD, CALIFORNIA · MULBERRY 2-6161 · CABLE "DONNER"

RECOMMENDED COMPUTING COMPONENT ASSORTMENTS FOR MODEL 3000 ANALOG COMPUTER

VERSATILE Component Selection

Applications: Full use of a single problem board, or good use of two boards with average problems on each.

Patch Cords

Quantity	Length	Stock Number	Price Each	Group Extension
30	4"	30-120-4	$ 1.60	$128.00
20	8"	30-120-8	"	
20	12"	30-120-12	"	
10	24"	30-120-24	"	

Plug-in Resistors (1%, deposited carbon)

Quantity	Value	Stock Number	Price Each	Group Extension
10	0.1 meg	30-101-10	$ 2.80	$182.00
10	0.2 meg	30-101-20	"	
10	0.5 meg	30-101-50	"	
10	1.0 meg	30-101-100	"	
10	2.0 meg	30-101-200	"	
5	5.0 meg	30-101-500	"	
10	10.0 meg	30-101-1000	"	

Plug-in Capacitors (Mylar)

Quantity	Value	Stock Number	Price Each	Group Extension
6	0.01 mfd	30-111-010	$ 6.50	$180.00
6	0.1 mfd	30-111-100	7.50	
6	1.0 mfd	30-111-1000	16.00	

Plug-in Potentiometers (1 turn, composition)

Quantity	Value	Stock Number	Price Each	Group Extension
6	100 K	3061	$ 7.20	$ 43.20
			TOTAL	$533.20

Prices FOB Factory, subject to change without notice.

January 1957

DONNER SCIENTIFIC COMPANY CONCORD, CALIFORNIA · MULBERRY 2-6161 · CABLE "DONNER"

RECOMMENDED COMPUTING COMPONENT ASSORTMENTS OR MODEL 3000 ANALOG COMPUTER

OPTIMUM I Component Selection

Applications: Highly complex problem on single problem board with wide choice of scaling, or full use of two boards.

Patch Cords

Quantity	Length	Stock Number	Price Each	Group Extension
35	4"	30-120-4	$ 1.60	$ 160.00
25	8"	30-120-8	"	
25	12"	30-120-12	"	
15	24"	30-120-24	"	

Plug-in Resistors (1%, deposited carbon)

Quantity	Value	Stock Number	Price Each	Group Extension
15	0.1 meg	30-101-10	$ 2.80	$ 238.00
10	0.2 meg	30-101-20	"	
10	0.5 meg	30-101-50	"	
15	1.0 meg	30-101-100	"	
10	2.0 meg	30-101-200	"	
10	5.0 meg	30-101-500	"	
15	10.0 meg	30-101-1000	"	

Plug-in Capacitors (Mylar)

Quantity	Value	Stock Number	Price Each	Group Extension
10	0.01 mfd	30-111-010	$ 6.50	$ 300.00
10	0.1 mfd	30-111-100	7.50	
10	1.0 mfd	30-111-1000	16.00	

Plug- Potentiometers (1-turn, composition)

Quantity	Value	Stock Number	Price Each	Group Extension
10	100 K	3061	$ 7.20	$ 72.00
			TOTAL	$ 770.00

Prices FOB Factory, subject to change without notice.

January 1957

RECOMMENDED COMPUTING COMPONENT ASSORTMENTS FOR MODEL 3000 ANALOG COMPUTER

OPTIMUM II Component Selection

Applications: Highly complex problem on a single problem board with wide choice of scaling, or full use of two boards. Substantially improved performance on integrating operations, due to use of polystyrene-dielectric capacitors.

Patch Cords

Quantity	Length	Stock Number	Price Each	Group Extension
35	4"	30-120-4	$1.60	$160.00
25	8"	30-120-8	"	
25	12"	30-120-12	"	
15	24"	30-120-24	"	

Plug-in Resistors (1%, deposited carbon)

Quantity	Value	Stock Number	Price Each	Group Extension
15	0.1 meg	30-101-10	$2.80	$238.00
10	0.2 meg	30-101-20	"	
10	0.5 meg	30-101-50	"	
15	1.0 meg	30-101-100	"	
10	2.0 meg	30-101-200	"	
10	5.0 meg	30-101-500	"	
15	10.0 meg	30-101-1000	"	

Plug-in Capacitors (Polystyrene)

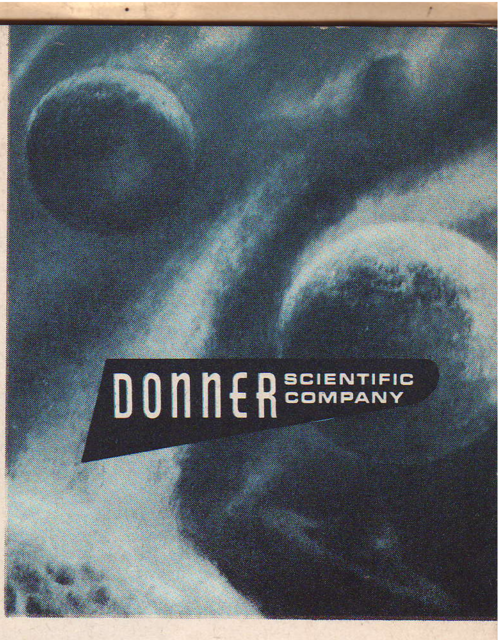
Quantity	Value	Stock Number	Price Each	Group Extension
10	0.01 mfd	30-110-010	$ 8.40	$462.00
10	0.1 mfd	30-110-100	9.80	
10	1.0 mfd	30-110-1000	28.00	

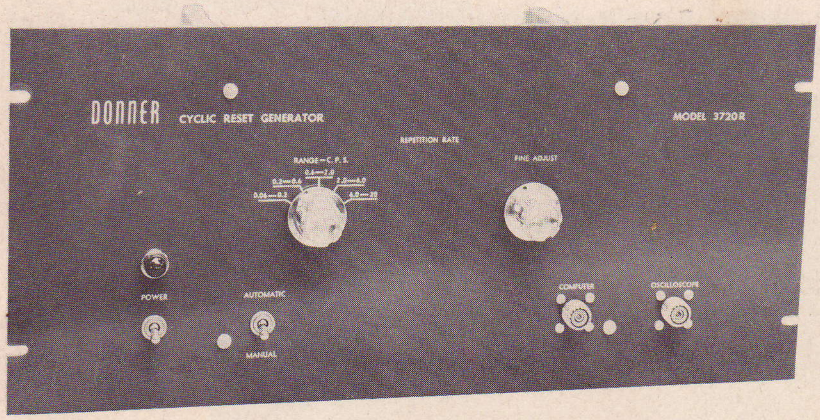
Plug-in Potentiometers (1-turn, composition)

Quantity	Value	Stock Number	Price Each	Group Extension
10	100K	3061	$7.20	$72.00
			TOTAL	$932.00

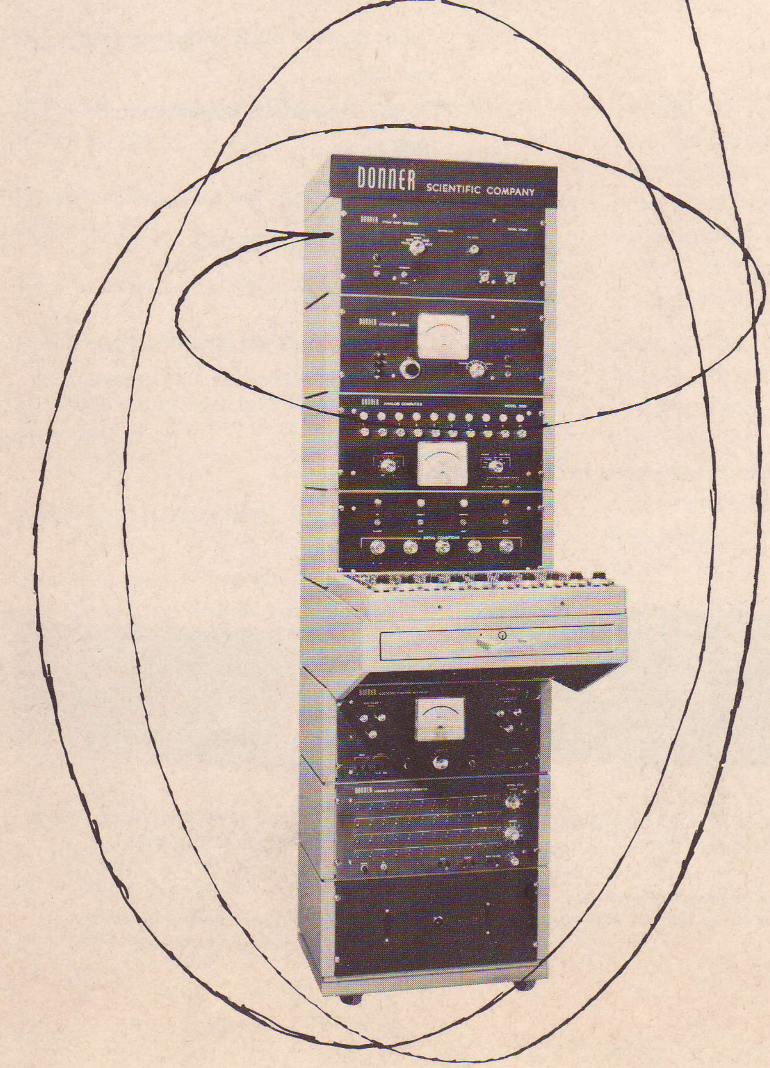
Prices FOB Factory, subject to change without notice.

4/58





DONNER MODEL 3720 CYCLIC RESET GENERATOR



This accessory to the Donner Model 3000 Analog Computer provides repetitive presentation of the problem solution on an oscilloscope or strip-chart recorder. It causes the computer output to be displayed at repetition rates smoothly adjustable from 0.06 cps to 20 cps. The Model 3000 is thus operated as a "high speed" computer. A front-panel switch disables the Cyclic Reset Generator when conventional manual operation of the computer is desired.

The Model 3720 is a simple pulse generator, connected to the COMPUTE-RESET relays in the Model 3000 Computer, and actuating these relays repetitively at a preset interval between 0.05 and 16 seconds. This instrument also delivers a sweep-initiating pulse to the sync input of the oscilloscope used, insuring display of the entire problem solution from "time zero."

In a typical analog computing facility, the basic Model 3000 Computer, together with the Model 3720 and other accessories, delivers its output to both an oscilloscope and a strip-chart recorder. Cyclic presentation on the oscilloscope is employed while problem parameters are varied to produce the solution expected or desired. Then, permanent records are made on the strip-chart recorder. Rapid simulation of an existing physical system, or conversely synthesis of an ideal system, is thereby facilitated.

FEATURES

- Resets, restarts computer automatically.
- Any repetition rate, 0.06 to 20 cps.
- Scope sync pulse for full display.
- Switch for automatic or manual operation.

January 1957

OPERATING PRINCIPLE

The Model 3720 incorporates a highly stable, free-running multivibrator operated from a regulated power supply. This circuit generates all pulses and step voltages required for operation of the computer relays and triggering the oscilloscope sweep. The repetition rate is smoothly adjustable, in five ranges, from 0.06 cps to 20 cps.

At the end of the preset computing interval, the Cyclic Reset Generator stops the progress of the solution and resets the computer initial condition voltages. A triggering pulse is then sent to the sync input of the oscilloscope, in advance of the next solution presentation. After the scope sweep starts, there follows a brief lapse proportional to the preset computing interval; this insures that the entire solution is displayed. The problem solution is then initiated by a step voltage applied to the computer. The entire cycle repeats at the repetition rate set on the RANGE and FINE ADJUST controls.

The AUTOMATIC-MANUAL switch provides either automatic repetition of problem solution or manual operation. The Model 3720 may thus be connected or disconnected at will, with no wiring or cabling changes. COMPUTER and OSCILLOSCOPE trigger output jacks are provided on both front and rear, to permit use of this accessory either separately or in modular assembly.

SPECIFICATIONS

Repetition Rate:

0.06 cps to 20 cps, smoothly adjustable, in 5 overlapping ranges:

1. 0.06 to 0.2 cps
2. 0.2 to 0.6 cps
3. 0.6 to 2.0 cps
4. 2.0 to 6.0 cps
5. 6.0 to 20 cps

Frequency Stability:

10% power line voltage change produces less than 5% shift in repetition rate.
Maximum drift 10% of set interval, after 15-minute warmup.

Output to Computer:

20 volts negative-going step voltage.
Internal impedance approximately 12,000 ohms.

Oscilloscope Trigger:

6 volts positive pulse with very short rise time.
Output impedance approximately 1000 ohms.

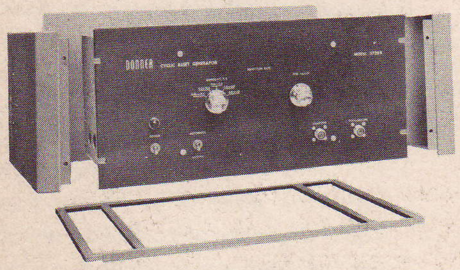
Tube Complement:

6C4, 6X4, 12AU7(2), 0B2.

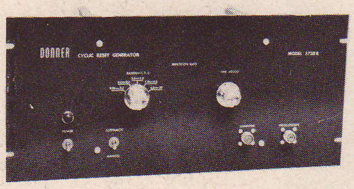
Power Requirement:

105-125 volts, 50-60 cps, 18 watts;
230 volts, 50-60 cps version, special order.

Technical specifications and prices subject to change without notice.



MODEL 3720 WITH STANDARD MODULE
Dimensions: 8¾ x 19 inch panel with Donner standard module.
Weight: 24 pounds (shipping).
Domestic price: $200.00, FOB Factory.



MODEL 3720-R RACK-MOUNTED
Dimensions: 8¾ x 19 inch rack-mounted panel, 12 inches deep.
Weight: 24 pounds (shipping).
Domestic price: $185.00, FOB Factory.

MODEL 3720-K WITH COMPLETE INDIVIDUAL CABINET
Dimensions: 22 wide x 10 high x 15 inches deep.
Weight: 26 pounds (shipping).
Domestic price: $215.00, FOB Factory.

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CONCORD, CALIFORNIA

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ANALOG COMPUTERS • TRANSDUCERS • TEST INSTRUMENTS

ELECTRONIC FUNCTION MULTIPLIER

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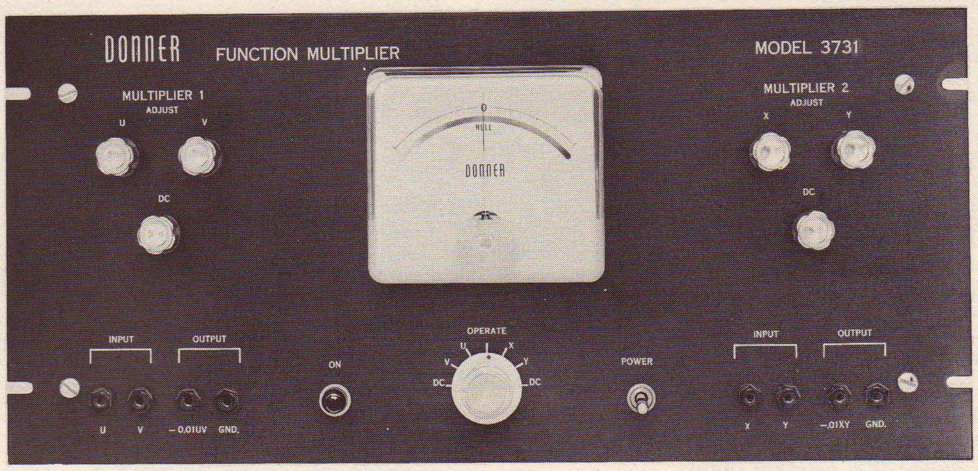
CONCORD, CALIFORNIA

MARCH, 1958



MODEL 3731 Electronic Function Multiplier

FEATURES

* *Products accurate within 0.25% of full scale (full scale = 200 v).*
* *Dynamic response excellent to 100 cps or higher.*
* *Very low drift and noise level.*
* *Built-in regulated power supplies.*
* *Modular construction for building-block assembly.*

APPLICATIONS

* *Generation of terms involving products in non-linear differential equations.*
* *Power terms in second and higher degree equations.*
* *Products of algebraic and trigonometric functions.*
* *Multiplication or division in non-computer work, such as on-line data processing.*

The Model 3731 is a two-channel multiplier which accepts four independent input voltages, U, V, X, and Y, each of which may be steady or continuously varying. Instantaneous products UV and XY are delivered with correct dc and ac components, proper algebraic sign, and accuracy within 0.25% of full excursion. The instrument is complete with its own power supply.

Each of the two channels of the Model 3731 accomplishes four-quadrant multiplication directly, where either signal voltage input to the channel may have any value over the operating range of ±100 volts. With simple external changes of signal connections and the use of one external operational amplifier, each channel of the Model 3731 can perform two-quadrant division, where one input signal may have any value over the range of ±100 volts but the other is restricted to the negative range. Four-quadrant division requires the addition of one Model 3750 Variable Base Function Generator.

With no servo motors or other moving parts, this all-electronic multiplier has excellent frequency response and low phase shift, permitting high-speed operation. The Model 3731 is normally used with Donner Analog Computers, to which it may be very simply connected.

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ANALOG COMPUTERS • TRANSDUCERS • TEST INSTRUMENTS

ELECTRONIC FUNCTION MULTIPLIER

MARCH, 1958

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CONCORD, CALIFORNIA

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With no servo motors or other moving parts, this all-electronic multiplier has excellent frequency response and low phase shift, permitting high-speed operation. The Model 3731 is normally used with Donner Analog Computers, to which it may be very simply connected.

OPERATING PRINCIPLE

The Model 3731 is an electronic function multiplier of the time-division type. Input U (or X) is sampled over an interval proportional to V (or Y) during a period of approximately 20 microseconds. Both inputs are appropriately biased to accommodate positive and negative signals. Several cycles of the rectangular output waveform are averaged, yielding the algebraic product of the two inputs. Because of the high sampling rate, accurate multiplication results for voltage inputs from DC to 100 cps and higher.

Two-quadrant function division (input V or Y always negative) is accomplished by placing the Model 3731 in the feedback loop of an analog computer operational amplifier. Four-quadrant division requires the addition of a Model 3750 Variable Base Function Generator, to accommodate V or Y inputs of either polarity.

SPECIFICATIONS

INPUTS U, X
Voltages between —100 and +100 volts. Input impedance 250,000 ohms.

INPUTS V, Y
Voltages between (a) —100 and +100 volts, for four-quadrant multiplication; (b) of negative polarity only (to —100 volts), for two-quadrant division; (c) —100 and +100 volts, for four-quadrant division (with necessary Model 3750). Input impedance 125,000 ohms.

OUTPUTS
—0.01 XY and —0.01 UV, in range of —100 to +100 volts at 5 ma maximum.

STATIC ACCURACY
Static error is zero for X = Y = O and increases to a maximum of 0.25% of full scale (full scale = 200 volts) near maximum output.

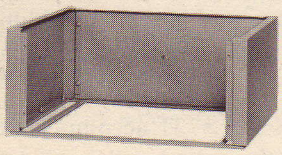
DRIFT
(1) After normal balance, drift (per hour) less than 0.1% of full scale.
(2) A full 10% shift in applied line voltage causes a drift in output voltage of less than 0.25% of full scale.

FREQUENCY RESPONSE
Within 0.5 db, 0 (dc) to 700 cps.

PHASE SHIFT
Less than 2.5° at 100 cps. Phase shift proportional to frequency below 100 cps.

OUTPUT NOISE
50 millivolts rms, maximum.

POWER REQUIREMENTS
105 - 125 volts, 60 cps, 175 watts; 105-125 volts, 50 cps version, special order.

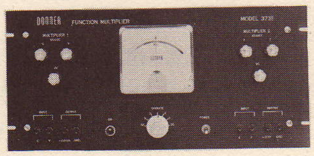


MODEL 3731
WITH STANDARD MODULE

Dimensions:
8¾ x 19 inch panel with Donner standard module

Weight:
43 pounds (shipping)

Domestic price:
$995 f.o.b. factory

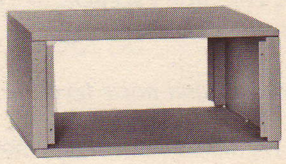


MODEL 3731-R
RACK-MOUNTED

Dimensions:
8¾ x 19 inch rack-mounted panel, 12 inches deep

Weight:
40 pounds (shipping)

Domestic price:
$980 f.o.b. factory



MODEL 3731-K
WITH COMPLETE
INDIVIDUAL CABINET

Dimensions:
22 wide x 10 high x 15 inches deep

Weight:
45 pounds (shipping)

Domestic price:
$1,010 f.o.b. factory

Data subject to change without notice.

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UNITED STATES AND CANADA

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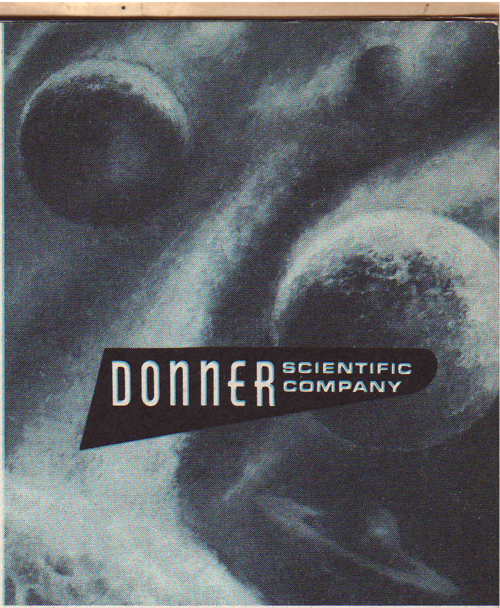
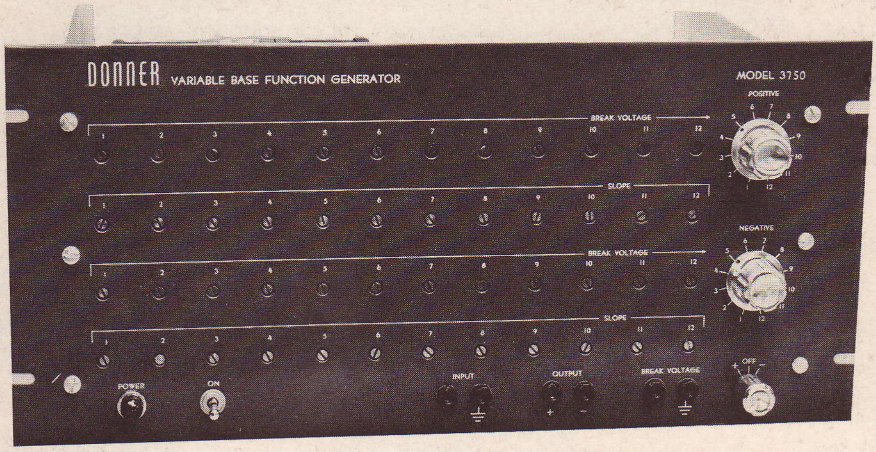
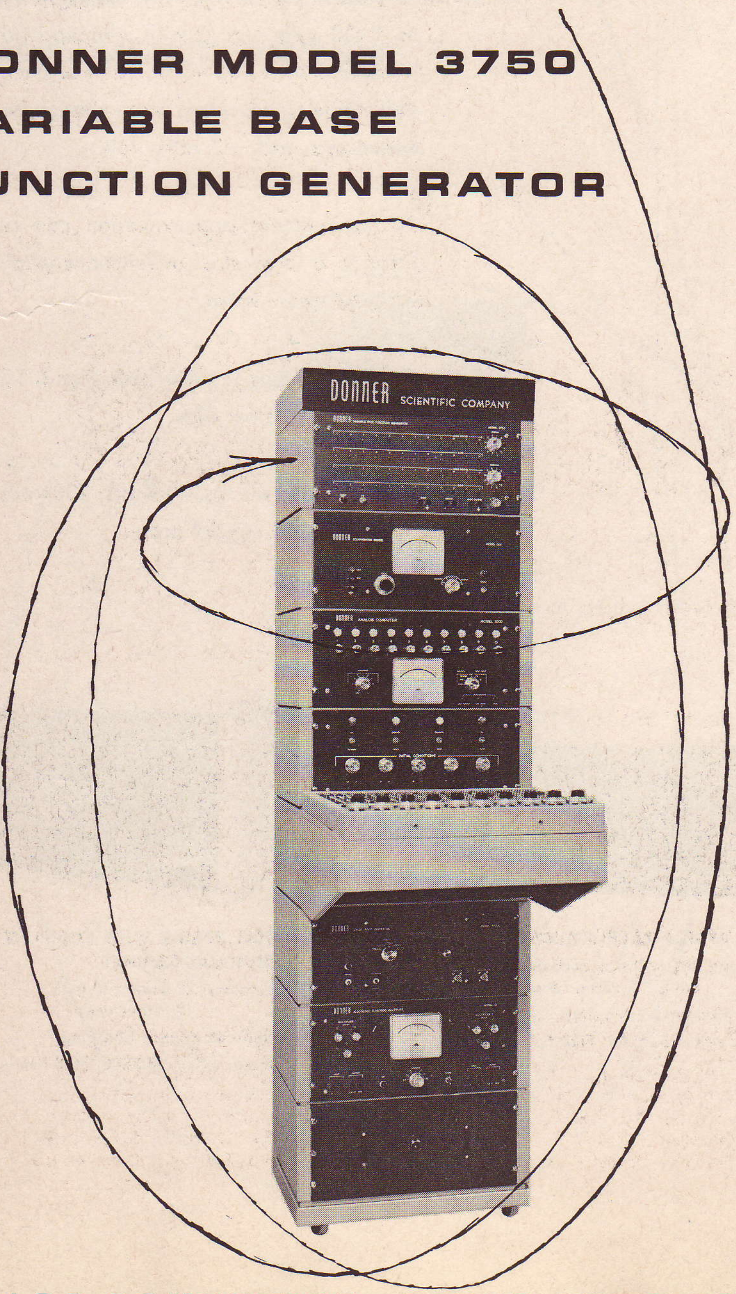
ANALOG COMPUTING EQUIPMENT





DONNER MODEL 3750 VARIABLE BASE FUNCTION GENERATOR



This instrument electronically synthesizes nearly any non-linear, single-valued curve by approximating it with a series of connected straight-line segments. A steady or varying input voltage, modified by the desired function, becomes the output voltage. Accuracy within 0.5% obtains for roots and powers, exponentials, reciprocals, trigonometric relations and many other functions.

The desired output/input characteristic is easily and rapidly set by front-panel controls. Two or more Function Generators may be cascaded for better approximation of very irregular curves. The Model 3750 is normally used with the Donner Analog Computer, to which it is very simply connected.

APPLICATIONS

- Generates arbitrary output/input relationships.
- Variable coefficients in computer problems.
- Generalized computer forcing functions.
- Dead-space or backlash simulation.
- Linearizing non-linear data.

FEATURES

- 24 independent, free line-segments.
- Slopes and intercepts individually adjustable.
- 0.5% approximation of most functions.
- 2 or more units may be cascaded.
- Built-in regulated power supplies.
- Modular construction for building-block assembly.

September 1956

OPERATING PRINCIPLE

The Model 5000 has a series-regulated power supply with a constant-current-fed voltage reference. The floating 100-volt output has exceptional stability and regulation. This output, polarity selected by a front-panel switch, is applied across a ten-turn, 20,000 ohm wire-wound potentiometer having excellent linearity and resolution.

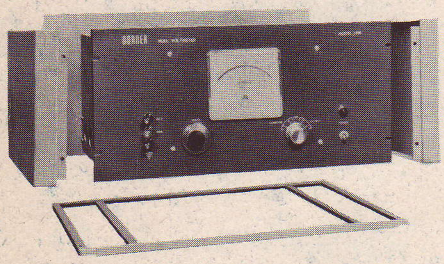
When the selector switch is set for OUTPUT, the full 100 volts is available at the 100V and GND terminals. The voltage at the potentiometer slider, as established by the dual-indicating dial, appears at the ARM terminal. Thus, any voltage up to 100 volts (either polarity) is delivered.

With the selector switch set at COMPARE, a null detector is inserted between the potentiometer slider and the ARM terminal. An external voltage applied to the GND and ARM terminals may now be matched precisely by adjusting the direct-reading potentiometer to produce a null. The exact ratio of an external series-resistor combination (i.e., the true attenuation coefficient of a loaded potentiometer, as used in an analog computer) is measured in the same way, but with reference voltage supplied from the 100V terminal. The null detector has sliding sensitivity: Application of a full 100 volts will not "peg" the meter, but in the immediate region of null a 0.5 microampere deviation is easily detected.

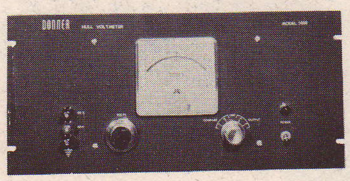
SPECIFICATIONS

- BASIC CIRCUIT
  - Voltage Across Potentiometer:
    100 volts ± 0.1%; may be readjusted to any value 95-105 volts.
  - Regulation:
    Less than 0.05% change for 10% line voltage shift or 10 ma output change.
  - Stability:
    Within 0.1% in 8 hours, 0.5% in one year.
  - Hum and Noise:
    2 millivolts rms, maximum.
  - Power Requirement:
    115/230 volts, 50-1000 cps, 18 watts.
- PRECISION VOLTAGE SOURCE
  - Output Range:
    0 to −100 or 0 to +100 volts, 10 milliamperes maximum.
  - Linearity:
    Within 0.05% full-scale value.
  - Resolution:
    0.01% full-scale value.
  - Source Impedance:
    5 ohms (0 or 100 volts) to 5000 ohms (50 volts).
- PRECISION COMPARATOR
  - Input Range:
    0 to −100 or 0 to +100 volts.
  - Accuracy:
    0.1% full-scale value for source impedances to 200,000 ohms; 1% to 2 megohms.
  - Null Detector:
    Sliding sensitivity, 0.5 microampere resolution.

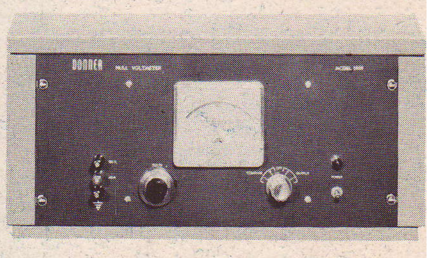
Technical specifications and prices subject to change without notice.



MODEL 5000 WITH STANDARD MODULE
Dimensions: 8¾ x 19 inch panel with Donner standard module.
Weight: 24 pounds (shipping).
Domestic price: $190.00, FOB Factory.



MODEL 5000-R RACK-MOUNTED
Dimensions: 8¾ x 19 inch rack-mounted panel, 12 inches deep.
Weight: 20 pounds (shipping).
Domestic price: $175.00, FOB Factory.



MODEL 5000-K WITH COMPLETE INDIVIDUAL CABINET
Dimensions: 22 wide x 10 high x 15 deep.
Weight: 26 pounds (shipping).
Domestic price: $205.00, FOB Factory.

DONNER SCIENTIFIC COMPANY
CONCORD, CALIFORNIA

ADVANCED INSTRUMENTATION

ANALOG COMPUTERS

SERVO ACCELEROMETERS

TEST INSTRUMENTS

DONNER SCIENTIFIC COMPANY

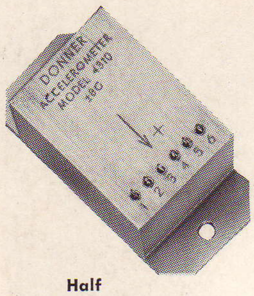
CONDENSED CATALOG

October 1957

LINEAR SERVO ACCELEROMETERS

STANDARD
VACUUM TUBE MODELS

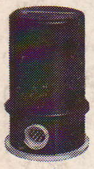
All Donner models (see table below), ruggedized and hermetically sealed, are adaptable to any acceleration measuring problem. They are built to withstand changes in calibration or zero shift resulting from high overloads, and because of their servo construction they inherently have a fast recovery time. Donner units are well suited to airborne applications such as telemetering, navigation, control and guidance systems. In a typical application, the Model 4143 exercises a control function in the inertial stabilization of helicopters.



Half actual size

MODEL 4310
TRANSISTORIZED
LINEAR SERVO ACCELEROMETER

- Accuracy—0.1% of full scale
- Linearity—Less than 0.05% deviation from best fitted straight line
- Resolution—Better than 0.0002% of full scale
- Weight—3.2 ounces
- Output—Up to ± 8 v dc for supply voltages of ± 15 v dc
- Power Requirements—150 milliwatts total input
- Competely portable—Battery operated



MODEL 4005

MODEL 4112

MODEL 4143

SPECIFICATIONS	MODEL 4310	MODEL 4112	MODEL 4143	MODEL 4005
Linearity	0.05%	0.1% Full Scale		
Resolution	0.0002%	Better than 0.001%		
Reproducibility	0.1%	0.05%	0.1%	0.1%
Ranges	±0.05G to ±50.0G	± 0.1G to ± 20.0G	±0.5G to ±10.0G	± 0.1G to ± 20.0G
Output, max.	± 8 volts	±15 volts	±45 volts	±35 volts
Companion Power Supply	Any ± 15 vdc unreg. supply	Model 4071 $250.00	Model 4071S $250.00	Model 4051 $175.00
Magnetic Shielding	Yes	Yes	No	Yes
Net Weight	0.2 lbs.	1.3 lbs.	0.8 lbs.	1.6 lbs.
Price (fob factory)	$450.00	$800.00	$490.00	$540.00

The Donner Model 4310 Precision Linear Servo Accelerometer is completely transistorized. A subminiature counterpart of standard Donner vacuum tube models, the Model 4310 delivers ± 8 volts of output at 0.1% accuracy. Output will drive a 0-1 ma recorder directly. Total input power requirement is ± 15 volts of unregulated DC power at milliwatt levels. Zero stability and linearity are enforced by the self-contained high gain servo system. MIL-USN silicon transistors allow operation from −40° C. to + 100° C. The Model 4310 is recommended for measurement and control functions in airborne, vehicular, and ground based applications.

TEST INSTRUMENTS

MODEL 1200
SINE WAVE GENERATOR

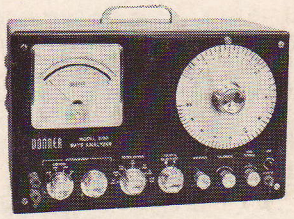
1 cps to 1 mc, plus overlap, in 6 decades. Less than 0.1% distortion. 600 ohms constant output impedance, no DC. 6 volts RMS maximum. 2% calibration accuracy. 0.5% stability. Regulated power supply.

Model 1200, $265.00

MODEL 1500
LOW FREQUENCY GENERATOR

0.01 cps to 1 kc, plus overlap, in 5 decades. True sinusoids, less than 1% distortion. Steep-sided square waves, 5 μsec rise time. 0-1 and 0-10 volts peak, fully metered output. 1% frequency stability, 1 db amplitude constancy.

Model 1500, $365.00
Model 1500R (Rack Mounting), $385.00



MODEL 2100
WAVE ANALYZER

30 cps to 50kc coverage, 3% calibration accuracy. 160 μv to 500 volts RMS full-scale sensitivity. Broad and narrow crystal filter selectivities. VTVM reads harmonics directly in percent and db. Simple operation, portability, reliability.

Model 2100, $495.00
Model 2100R (Rack Mounting), $515.00

DONNER SCIENTIFIC COMPANY
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