

Instruction Manual

MODEL 3500

ANALOG COMPUTER
(Portable)

Manufactured By

DONNER SCIENTIFIC COMPANY

Concord, California

A Division of

Systron-Donner Corporation

January 1960

Serial No. _____



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CONCORD, CALIFORNIA

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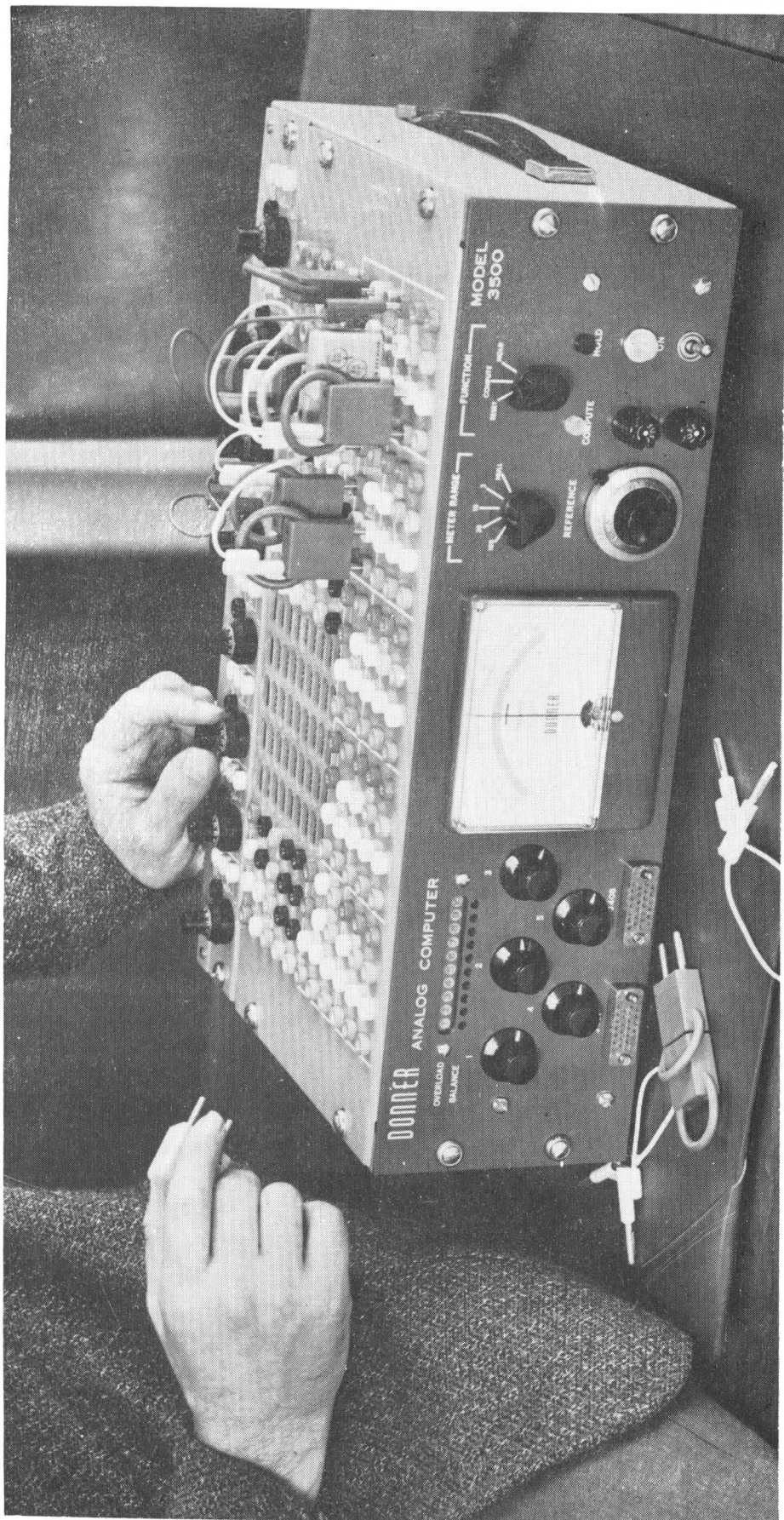


Figure 1 — Model 3500 Portable Analog Computer
(with Auxiliary Potentiometer Strip)

MODEL 3500

RACK MOUNTING INSTRUCTION

Reference instruction manual:

Fig. 4, page 24

Fig. 2, page v

To prepare unit for rack mount - Fig. 4.

Step 1. Remove (10) panel mtg. screws and cup washers retaining:

- (a) Control Panel.
- (b) Patch panel.
- (c) Potentiometer Panel.

retain hardware for rack mounting

Step 2. Remove (4) mounting screws and washers retaining:

- (a) Rear trim strip.

Step 3. To remove side panels.

Release the (2) wing screws on rear apron allowing it to fall back.

Remove from inside rear flange (2 per side) remaining side panel screws and washers. Side panel is now removable.

To rack mount - Fig. 2

Close (2) wing screws on rear apron.

Caution - Do not remove protective mesh from fan opening.

Assemble panels to rack per fig. 2, using all hardware from Step 1. Unit is now ready for operation per manual, Programming and Operation Section, beginning page 11.

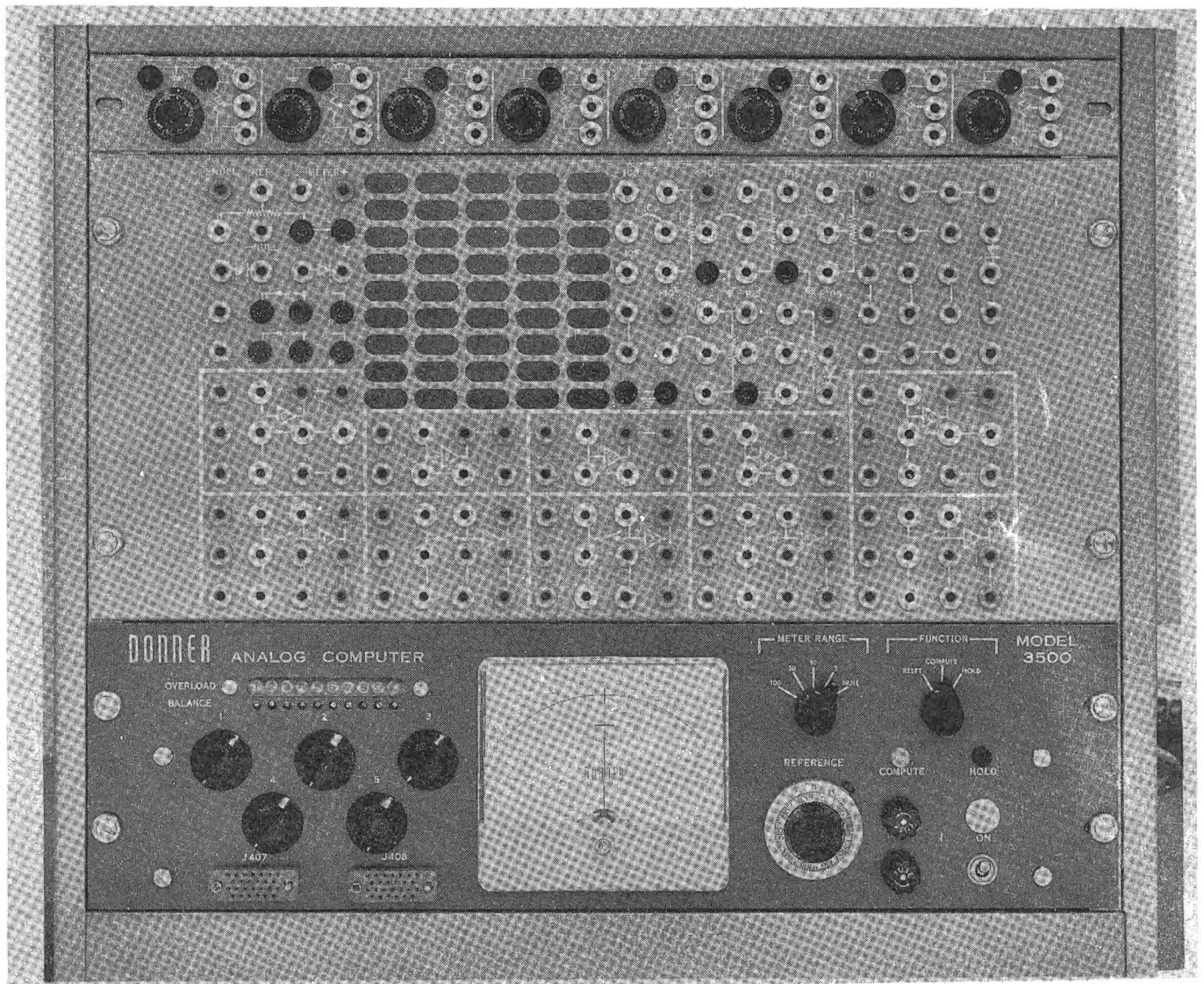


Figure 2 - Model 3500 In Rack Mount

Model 3500

v

INTRODUCTION

1 - General Description

The Model 3500 is a low-cost, portable, analog computer with very high performance characteristics. Its ten-amplifier capacity (five integrators and five summers) is sufficient for handling a large majority and a wide variety of computer applications. The computer is completely self-contained within a small case and requires only a selection of plugin components (resistors, capacitors, and patchcords) to be fully operational.

The striking simplicity of the overall design reduces all operations to fundamental steps which can be readily understood by persons unfamiliar with electronics, without sacrificing accuracy or versatility. Circuit components are presented on the problem board in a highly intelligible manner, giving an immediate visual analogy between the physical computing circuit and the problem diagram.

In addition to fulfilling the important need for a portable computer easily accessible to the individual engineering-designer and scientist, the Model 3500 is suitable for widespread applications for automation in the monitoring and control of industrial processes and is ideal for student lab work and classroom demonstration. For this latter purpose, the computer may be mounted in a display-type rack, as shown in Figure 2, and the operational Model 3530 Remote Problem Board set may be employed. Each of these units commands up to five amplifiers in the computer independently of the second unit, thus converting the Model 3500 into separate small computers. By means of the auxiliary Model 3520 Multiple Control Unit, two or three portable computers may be slaved together, increasing the amplifier capacity to twenty or thirty. This accessory also provides automatic reset for the computers, which enables one to repeat the solution continuously as for displaying on an oscilloscope.

The Model 3500 may be used directly as a complete DC amplifier system by means of the amplifier input-output connectors on the front panel. It can also double as a sine-cosine function generator, a low-frequency signal generator, a wave analyzer and a precision null volt-meter. (Circuits for these applications are described in the appendix.)

2 - Computer Applications

In its primary role, the basic analog computer is used to give accurate solutions of linear (and certain classes on non-linear) differential equations and transfer functions. With auxiliary analog instruments, including function generators, servo or electronic multipliers, and transport time delay generators, general and complex non-linear equations may be solved. The operational amplifiers in the computer perform the functions of algebraic addition, subtraction, multiplication by a constant, sign-changing, integration, and differentiation.

Being an analog device, whereby physical quantities are represented by computer voltages, the computer may be used as an accurate model of an arbitrary physical system, thus saving immeasurable time in engineering design, construction, and analysis. System parameters are varied by adjusting the computer potentiometers.

This analog computer can make an invaluable contribution for study, demonstration and research in a wide variety of fields. A partial list of subjects includes:

AERODYNAMICS

CHEMICAL KINETICS

ELECTRICAL ENGINEERING

- antenna design
- filter network design
- servo system analysis
- Lissajous figures
- Modulation
- damping factor
- AC circuit fundamentals
- Fourier Analysis
- Matrix Analysis
- frequency, phase, and time response

MECHANICAL ENGINEERING

- simulation of dynamic systems
- structural analysis

PETROLEUM ENGINEERING

MATHEMATICS

- differential equations
- simultaneous algebraic equations
- partial differential equations
- LaPlace transforms
- logarithmic decrements
- basic meaning of derivative and integral of a variable
- quantitative study of equations on a parametric basis

METEOROLOGY

MEDICAL AND PSYCHOLOGICAL RESEARCH

- human environment
- cardio-vascular system
- nervous system
- orthopedics
- genetics
- virology

CLASSICAL PHYSICS

- trajectories of freely falling bodies
- equations of simple harmonic motion
- damping factor
- heat transfer analysis
- fluid mechanics
- optical ray tracing

NUCLEAR PHYSICS

- radio-active decay series
- electron trajectories
- operation of a cyclotron

REACTOR KINETICS

STATISTICS

- auto- and cross-correlation
- economic forecasting

3 - Detailed Description

The basic components of the computer are the ten high-gain DC amplifiers which rival in performance those used in computers many times more costly. They are offered with an option of chopper-stabilization, or without stabilization. At any time, the unstabilized amplifier can be converted in the field or at the factory by adding components to the printed circuit board. The voltage range of these amplifiers is between +100V and -100V with 4 milliamperes maximum output current. (See "Specifications" for complete data.)

The panel meter of the Model 3500 has four direct-reading scales and a null voltmeter function which permits measurements and settings to the nearest 0.1 volt (equal to an accuracy of three significant figures). Five potentiometers are available for initial condition adjustments or coefficient settings. These may be supplemented by the optional Models 3570 or 3571 "pot" strips or individual plug-in potentiometers.

A set of compute-reset contacts located on the problem board permits two of the summing type amplifiers to be converted to integrators and also may be used to synchronize a Donner Model 3400 Computer or other auxiliary equipment with the Model 3500. Plug-in problem board components supplied for the Model 3500 include encapsulated resistors of common values between 0.1 and 10 megohms with either 1% or 0.1% tolerance, and 0.1% polystyrene capacitors of 0.01, 0.1 and 1.0 microfarad values. (See Appendix for complete listing.) A highly regulated power supply furnishes all necessary power for the DC amplifiers as well as precision reference voltages for the null voltmeter. The Model 3500 also includes positive and negative bias voltage supplies which are used as sources for problem constants, amplifier balancing and overload indication circuitry, and four diode limiters for special computing circuits.

4 - General Specifications

Detailed specifications for individual components are given in supplementary manuals.

Stabilized Amplifiers (with 100K resistors)

short-term stability: $\pm 200 \mu\text{v}$

60 cps noise: 5mv, r.m.s.

Frequency response:

resonant at 60kc

-3db at 85kc

drift (as unity integrator):

$\pm 150 \mu\text{v}/\text{second}$

Meter

Null accuracy: ± 0.1 volt

direct ranges: $\pm 3\text{V}$, 10V, 30V, 100V

Input Power

115V or 230V, $\pm 10\%$, 50-60 cps

single phase, 225 watts

Size: $5\frac{7}{8}$ " h by $12\frac{1}{2}$ " d by 19" w

Shipping Weight: 28 lbs.

MODEL	DESCRIPTION
3731 Electronic Function Multiplier	Provides two channels of multiplication. Each produces output voltage equal to $.01XY$ where both X and Y may vary between -100 and +100 volts.
3735 Electronic Function Multiplier (High-Accuracy)	
3732 Quarter-Square Multiplier	Diode-type multiplier with characteristics similar to Model 3731.
3750 Variable Base Electronic Function Generator	Uses 24 biased diodes to simulate electronically the curve of any single-valued, continuous function.
Fixed-Function Generators	Series of plug-in circuit cards; each set at factory to simulate a single function.
3770 Transportation Delay Generator	Provides two separate or cascaded channels for accurate time delay of low frequency signals. Three available ranges of delay cover .005 to 20 seconds.
3121 Amplifier Receptacle	Mounts up to five dual amplifiers for use as auxiliaries.
3103 Dual Amplifier	Chopper-stabilized type used in the Model 3500.
3104 Dual Amplifier	Identical to 3103, but chopper-stabilizer circuit is omitted.
3570 Potentiometer Strip	Contains 8 single-turn composition potentiometers.
3571 Potentiometer Strip	Contains 8 ten-turn wire-wound potentiometers.
3520 Multiple Control Unit	Controls 2 or 3 Model 3500 computers for slave operation. Provides automatic reset.
3530 Remote Problem Board Set	Each board independently commands five amplifiers.
Plug-in Components	Patchcords Resistors, 1%, deposited carbon and 0.1% wire-wound. Capacitors, 0.1% polystyrene Potentiometers, individual, single turn, 0.1 megohms (part No. 3961) Operational relay, double-pole, double-throw (part No. 3965)
(See Appendix for Further details)	

COMPUTER THEORY

Outline of Computer Operations for Non-Electronics People

NOTE: Throughout the succeeding chapters cross-references will be made to facilitate use of the manual. For example, "(see 3.2)" indicates paragraph reference within the same chapter; "(see III-3.2)" refers to another chapter.

1 - General

A detailed understanding of analog computers is not necessary to solve the majority of problems on the Model 3500. The supplementary theory booklet furnished with the computer is intended as a comprehensive reference, and may serve as the basis for a course in analog computation. However, the brief outline presented here, together with the supplementary examples in the appendix, will acquaint the novice with the essential steps. The steps of computer operation are:

1. Arrangement of problem equations (drawing of preliminary diagram).
2. Magnitude and time scaling, with transformation to machine equations, if required.
3. Preparation of a computer circuit diagram.
4. Programming the computer problem board and setting problem parameters according to the diagram.
5. Recording or observing the solution.

It is usually helpful to make a preliminary shorthand diagram after step 1, which eventually may take the place of Step 3.

2 - Computer Operations and Notation

The analog computer performs operations with varying d.c. voltages which can be made to obey the same set of mathematical equations used to describe a given physical system. Thus, it can be used as a convenient electrical model of the system to be studied, giving continuous, dynamic solutions in real, "fast", or "slow" time. Problems most suitable to the analog computer may involve:

1. Ordinary differential equations with constant coefficients.

$$a \frac{d^2y}{dx^2} + b \frac{dy}{dx} + cy = f(x)$$

(single equations or sets)

2. Algebraic equations (roots of polynomials, matrices, simultaneous linear equations).
3. Partial differential equations, e.g.:

$$\text{Heat Flow } \frac{\partial^2 \theta}{\partial x^2} = \frac{1}{h^2} \cdot \frac{\partial \theta}{\partial t}$$

4. Boundary value problems (all initial conditions not known) e.g.:
vibration problems, or bending of beam supported at both ends.
5. Implicit solutions

$$F(x, y, z) = 0$$

6. Non-linear problems (with auxiliary equipment), e.g.:

$$a \frac{d^2y}{dx^2} + b \frac{dy}{dx} + \sin y \cdot \dot{y} = f(x)$$

also discontinuous non-linearities such as friction, back-lash, limiting.

7. Real-time physical simulation in which the computer substitutes for a component in a physical system.
8. Data processing (in-line or delayed), integration, algebraic calculations auto- or cross-correlation.





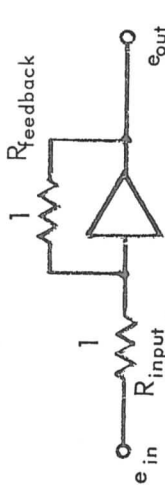

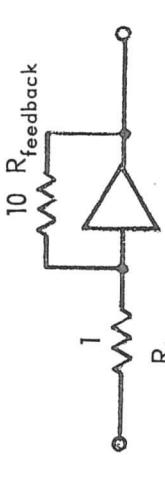

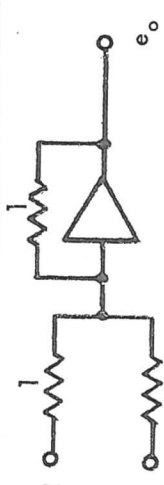
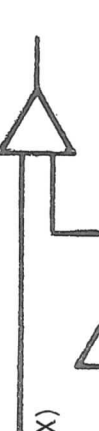
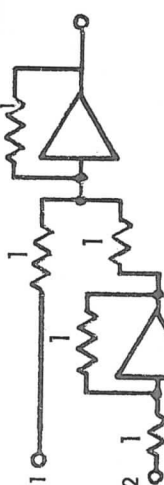

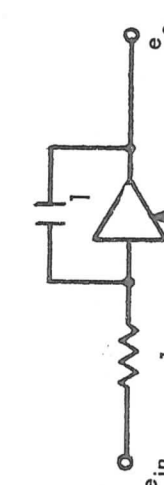

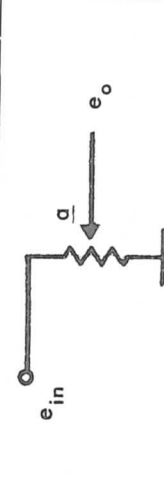
The basic component is the operational amplifier, symbolized . This component performs the operations listed in Table I when connected with passive components (resistors  and capacitors ) , as shown in the "Computer Circuit Symbol" column. After one gains familiarity with circuit connections, he may use only the simplified operational symbols (shown in the center column) as shorthand for the circuit symbols. Further explanation is given below. Before attempting to demonstrate the examples presented in this section, one should become acquainted with the method of connecting and adjusting components given in the succeeding chapters, "Programming and Operating the Computer".

TABLE I - COMPUTER NOTATION

OPERATIONS	OPERATIONAL SYMBOL	COMPUTER CIRCUIT SYMBOL	TRANSFER FUNCTION
A. Sign-changing $-1 \cdot X$			$e_o = -e_{in}$
B. Multiplication by a Constant $-10 \cdot X$			$e_o = -10e_{in}$ $(e_o = \frac{-R_f}{R_{in}} \cdot e_{in})$
C. Summing $-(X + 5Y)$			$e_o = -(e_1 + 5e_2)$
D. Subtraction $-(X - Y)$			$e_o = -(e_1 - e_2)$
E. Integration $-\int Xdt + K$			$e_o = \frac{-1}{RC} \int e_1 dt + K$
F. Coefficient $a \cdot X$			$e_o = a \cdot e_{in}$

3 - Sign-Changing (Inverting)
and Multiplication by a Constant

In terms of the actual voltage change performed by the computer circuit in examples A and B (Table 1), the expression or transfer function is:

$$e_{out} = \frac{-R_f}{R_{in}} \cdot e_{in} \quad \text{where } e_{in} \text{ may be constant}$$

or variable.

R_f and R_{in} are fixed-value plug-in resistors connected physically as explained in Chapter III, par. 4.2a. If $R_f = R_{in}$, then $e_o = e_{in}$. When the ratio R_f/R_{in} has some value other than 1, as in example B of Table 1, multiplication or division by a constant is performed. Besides the discrete ratios obtainable with the available resistors (see Appendix for a complete list of values), multiplication or division by any value of constant may be achieved by using an adjustable coefficient potentiometer in conjunction with the amplifier (see 6.1).

4 - Summing and Subtraction

With several input sources, as in example C (Table 1), the expression for the operational amplifier circuit becomes:

$$e_o = - (e_1 + e_2 + \text{etc.}) \quad \text{if all resistors are equal,}$$

or

$$e_o = - (e_1 \frac{R_f}{R_1} + e_2 \frac{R_f}{R_2} + \text{etc.})$$

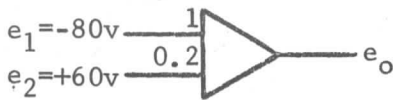
if resistor ratios other than 1 are selected.

By combining the summing and inverting operations (examples A and C), subtraction of two quantities is made possible, as illustrated in example D.

Demonstration Problem A

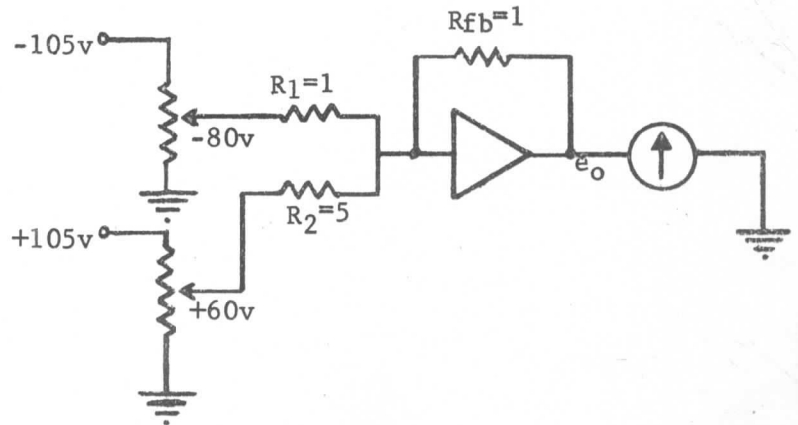
After reading the following chapter on "Programming and Operating", connect the circuit shown below and confirm that e_o measures 68 volts.

OPERATIONAL DIAGRAM



Actual problem board connections are shown under "Demonstration Problem A Connections" in the Appendix. Note that e_1 and e_2 are obtained from the +105 and -105 fixed bias terminals by means of potentiometers (see III-4.3C). Use of the meter is described in III-3.

CIRCUIT DIAGRAM



If a capacitor C is substituted for resistor R_f, as in example E of Table 1, the amplifier electronically performs integration with respect to time and the expression for the circuit can be written:

$$e_o = - \int_0^t e_{in} dt + K, \text{ if } R \cdot C = 1$$

(Normally R = 1 megohm and C = 1 microfarad)

NOTE: The value of R is always calculated in megohms (M) and C in microfarads (mfd).

"K" is the initial condition constant which is inserted electrically as a preliminary charge on the capacitor when the computer is placed in "Reset"; that is, before the input voltage is applied to the amplifier by turning the function switch to "Compute". (See III-4.3a)

Analogous to example C of Table 1, if an integrating amplifier has several inputs with different values of R, the expression is:

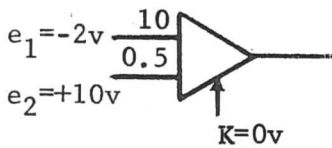
$$e_o = - \int_0^t \left(\frac{e_1}{R_1 C} + \frac{e_2}{R_2 C} + \dots \text{etc.} \right) dt + K$$

which tells us that the amplifier both sums and integrates at the same time.

Demonstration Problem B

Connect the circuit shown below:

OPERATIONAL DIAGRAM

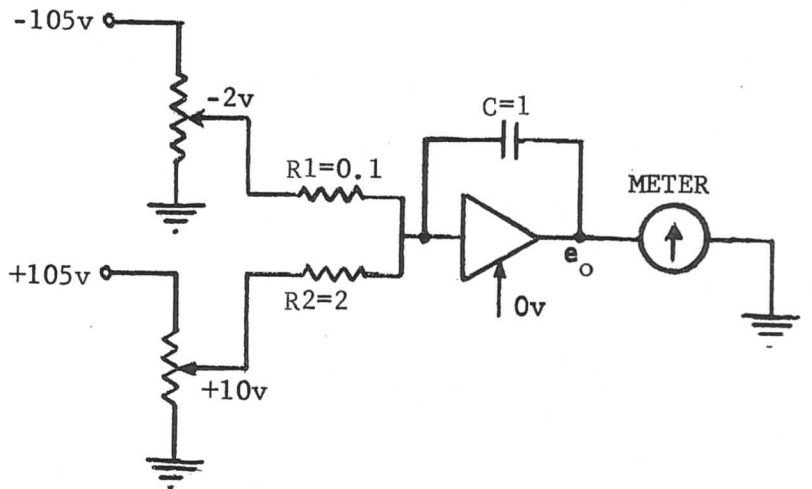


Substituting the given values of e, R, K, and C into the equation in paragraph 5 yields:

$$e_o = - \int_0^t \left(\frac{-2}{0.1} + \frac{10}{2} \right) dt + 0 = 20t - 5t = 15t$$

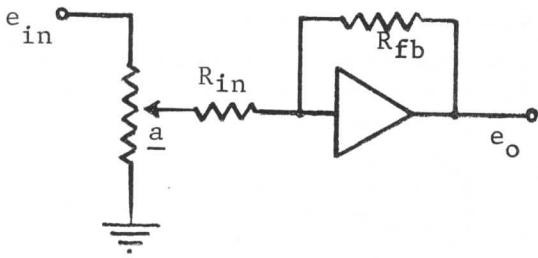
The result may be observed dynamically on the 100V direct-reading scale of the meter when it is connected to the amplifier output. e_o will increase 15 volts per second for over six seconds after the computer is placed in the "Compute" mode until the amplifier reaches saturation (+100 volts output) at which time the overload lamp will light and the solution is no longer valid. Refer to the "Demonstration Problem B Connections" diagram in the Appendix.

CIRCUIT DIAGRAM



6 - Coefficients

6.1 **Fractional Gain:** The coefficient potentiometer is normally used as shown below as a means to obtain a fractional part of the amplifier input voltage.

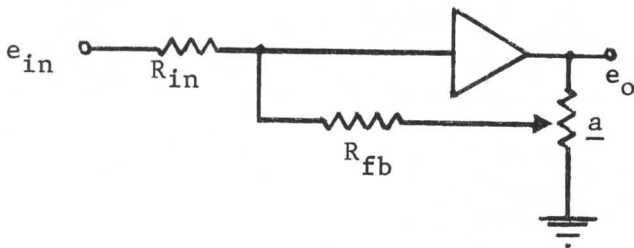


The output voltage of the amplifier, therefore, may be expressed as:

$$e_o = - a \cdot \frac{R_f}{R_{in}} \cdot e_{in}$$

where a is the desired fraction (always less than unity) established by the setting of the potentiometer. Whereas the gain of an amplifier is usually limited by choice of R_f and R_{in} to the integers 1, 2, 5, 10, or their reciprocals, any fractional value of these integers may be established by the coefficient a. (See III-4.3B for technique of adjustment.)

6.2 **Reciprocal Coefficients:** The coefficient potentiometer is also commonly used in the circuit shown below, yielding gains greater than unity.



The transfer function for the amplifier circuit is:

$$e_o = \frac{-1}{a} e_{in} \quad \text{if } R_f = R_{in}$$

The gain of the circuit is seen to be inversely proportional to potentiometer setting a. In this circuit, a should not be set to a value of less than 0.1. To obtain a gain greater than 10, change the ratio of R_f/R_{in} as in par. 3.

7 - Solution of Differential Equations

By combining the basic operations described in Table 1, the computer is able to perform one of its basic roles, the solution of linear differential equations. A simple, typical problem occurring frequently in mechanical, electrical, and hydraulic systems, which can be represented by a general second order differential equation, will serve to illustrate the common approach to problem preparation:

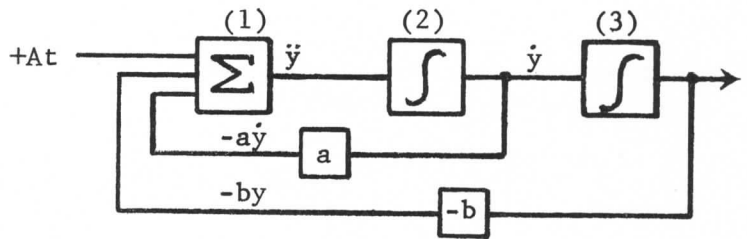
$$\text{The equation: } \frac{d^2y}{dt^2} + a \frac{dy}{dt} + by = At$$

which can be abbreviated: $\ddot{y} + a\dot{y} + by = At$

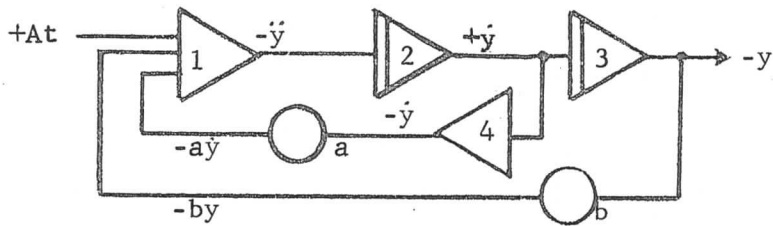
Since the computer may perform successive integration, generating lower order derivatives from the highest order derivative, the equation is normally put into the form:

$$\ddot{y} = -a\dot{y} - by + At$$

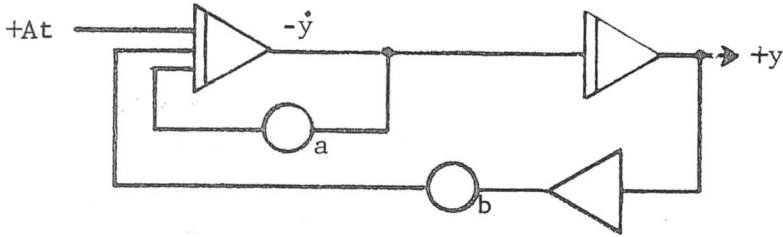
This equation can be represented by the following block diagram:



The computer solution is realized by interconnecting components to perform the operations described by the block diagram. The block diagram can be translated immediately into the following computer diagram, using operational symbols. (Remember that each amplifier produces a sign-change!)



Note that if the term \dot{y} is not actually of interest, the summing and integrating operations could be performed simultaneously by one amplifier. The circuit diagram would then become:



8 - Problem Scaling Illustrations

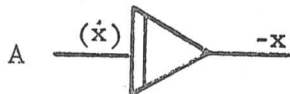
The following illustrations should be studied and then demonstrated, referring to the following chapter on "Programming and Operating the Computer" as necessary.

Demonstration Problem C

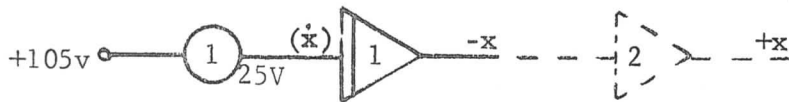
Consider the first-order differential equation representing uniform linear motion:

$$\text{velocity} = \frac{dx}{dt} = A \quad \text{or} \quad \dot{x} = A \quad (\text{eq. 1})$$

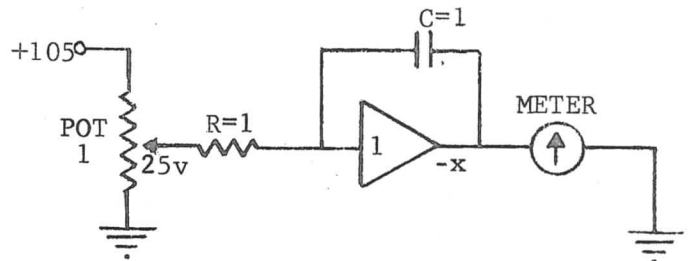
The computer diagram for "solving" this equation would be simply:



The constant input A, representing constant velocity, is obtained from the fixed 105 volt bias by setting a potentiometer for the desired fractional output value. Using $A = 25$ ft./second, the complete operational diagram becomes:



Potentiometer ① is adjusted for an output of 25 volts (see III-4.3c.). Amplifier ② may be used if it is desired or necessary to read x with its true polarity. The equivalent circuit diagram for the problem is given below, and the actual problem board connections are shown on the "Demonstration Problem C Connections" diagram in the Appendix.



From equation (1) we know that the solution is $\int dx = \int A dt$ or $X = At + K$ (eq. 2)

K is the initial condition, X_0 . For this example set $X_0 = 0$ ft. (see III-4.3a). As seen from equation (2), the output can be expected to increase linearly from zero to -100 volts in four seconds, beginning at $t = 0$ when the computer is placed in the "Computer" mode. When the amplifier output exceeds 100 volts, it may saturate (the overload lamp lights) and the solution is not valid beyond this point.

Magnitude Scaling

If, in Example C, $A = 200$ feet/second, and we wish to compute X for a second, it will not be possible to represent the problem quantities by voltages of equal value since the maximum range of the amplifiers is ± 100 volts. In this case, it is necessary to scale the magnitude of A and consequently, X. Let us use $A/2 = 100$ volts, resulting in an output of $-X/2$. (If K has some value other than zero, it would have to be scaled down to $K/2$ also.) The computer equation is:

$$\frac{1}{2} \frac{dx}{dt} = \frac{A}{2} \quad (\text{eq. 3})$$

To achieve the 1/2 magnitude scaling, it is only necessary to readjust potentiometer 1 for an output of 100 volts. The output $-X/2$ will now increase linearly from zero to -100 volts in only one second, representing an actual increase in X to 200 feet for the same period.

Time Scaling

The one second "real-time" computing period of this example may not be convenient for observing the solution on the meter, oscilloscope, or recorder - whichever is being used for monitoring. Indeed, for some problems it may be desirable to simulate a phenomenon lasting only a few millionths of a second. This would not be possible without time-scaling the computer problem to within the response range of the computer and the recorder. On the other hand, it may be desirable to program a phenomenon which lasts many hours in real time to occur within a relatively brief period in the computer.

In the present example, let us slow up the solution from one second to ten seconds.

$$\text{Let } t \text{ (real time)} = 0.1T \text{ (machine time)}$$

$$\text{so that } \frac{dx}{dt} = 10 \frac{dx}{dT}$$

Substituting in equation (3):

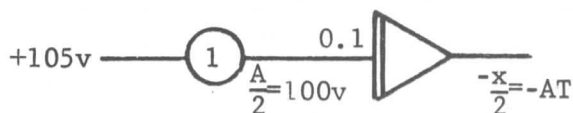
$$10 \frac{1}{2} \cdot \frac{dx}{dT} = \frac{A}{2}$$

$$\text{and } \frac{X}{2} = \frac{1}{10} \cdot \frac{A}{2} T \quad (\text{eq. 4})$$

$$\text{where } T = 10 t$$

These equations tell us that by using an amplification factor (or "gain") of 1/10 of the input $A/2$, the output will increase at 1/10 the former rate and we will have achieved a time-scale transformation of 10.

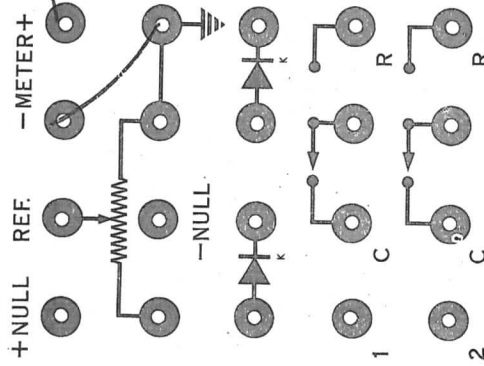
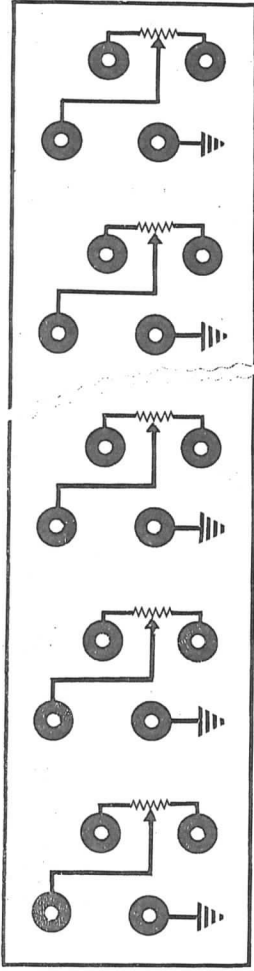
It is not necessary to change the setting of potentiometer 1 to achieve the time scaling. Instead, change the amplifier gain from a value of 1 ($1/RC = 1$, where $R = 1$, $C = 1$ mfd.) to 1/10 ($1/RC = 1/10$, where $R = 10M$, $C = 1$ mfd.). (Refer to Table 1, step E). The operational diagram is:



If no 10 megohm resistor is available, then it will be necessary to reset the potentiometer to 1/10 its initial output value, or 10 volts. The output $-X/2$ will now increase from zero to -100 volts in ten (T) seconds, representing a change in X of zero to 200 feet in one (t) second of real time.

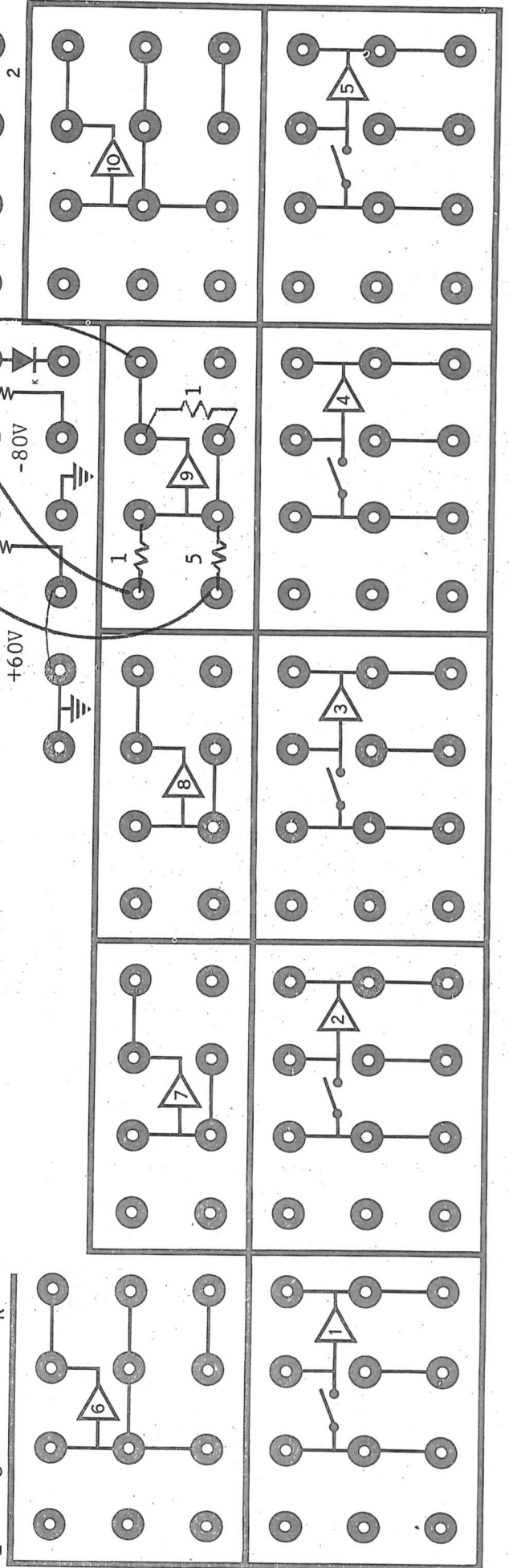
Additional demonstration problems are presented in the Appendix.

AUXILIARY
POTENTIOMETERS

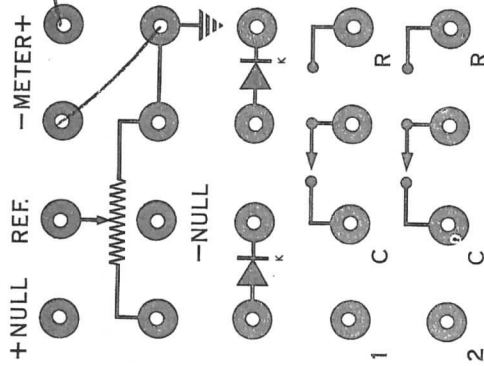
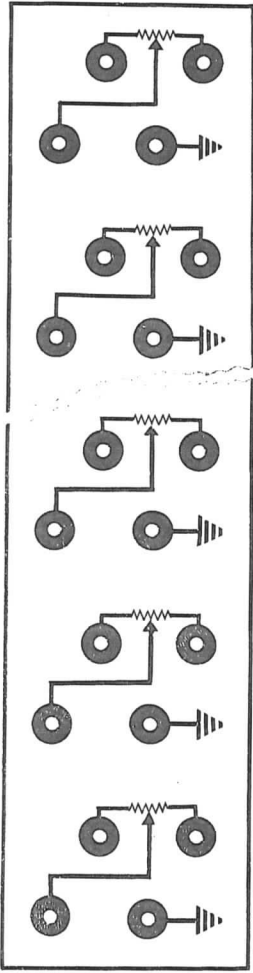


DONNER SCIENTIFIC COMPANY
MODEL 3500
PROBLEM BOARD

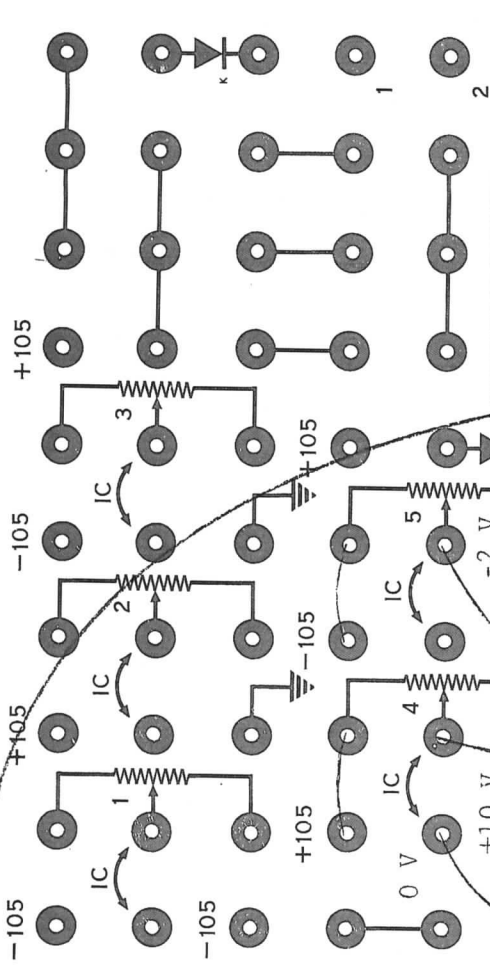
DEMONSTRATION PROBLEM A
CONNECTIONS



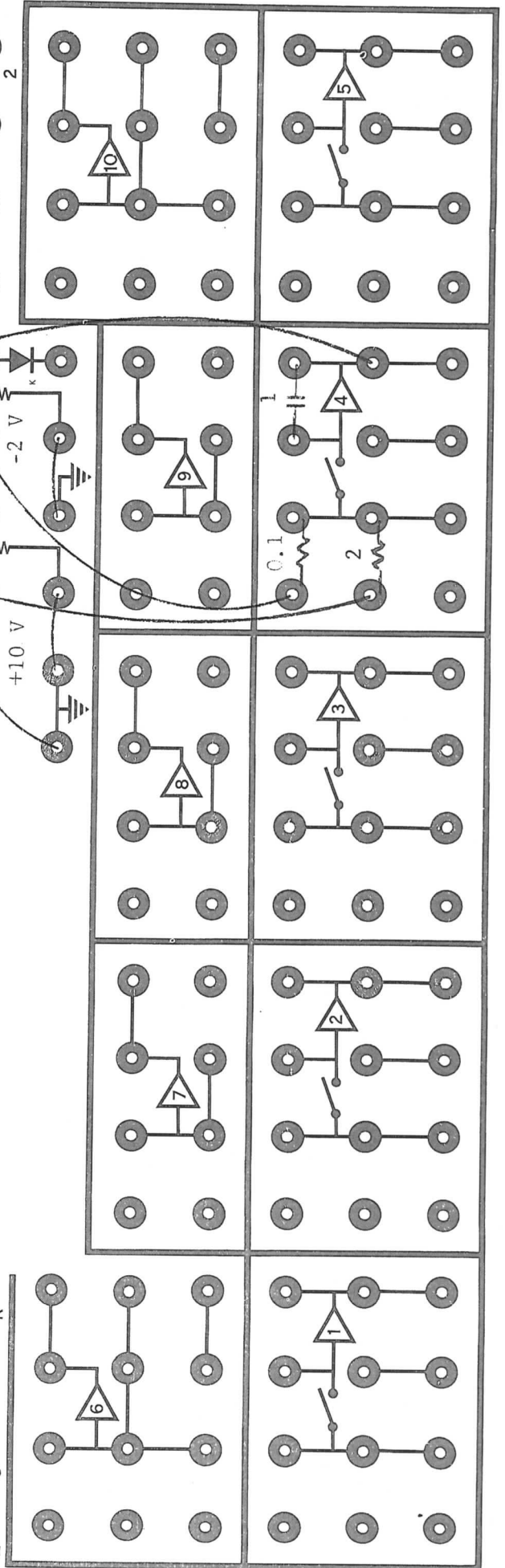
AUXILIARY
POTENTIOMETERS



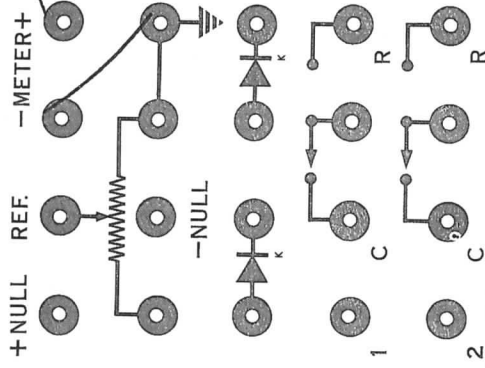
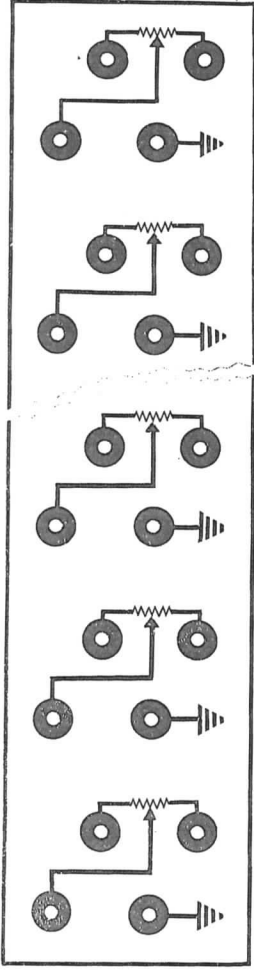
DUNNEN SCIENTIFIC COMPANY
MODEL 3500
PROBLEM BOARD



DEMONSTRATION PROBLEM B
CONNECTIONS

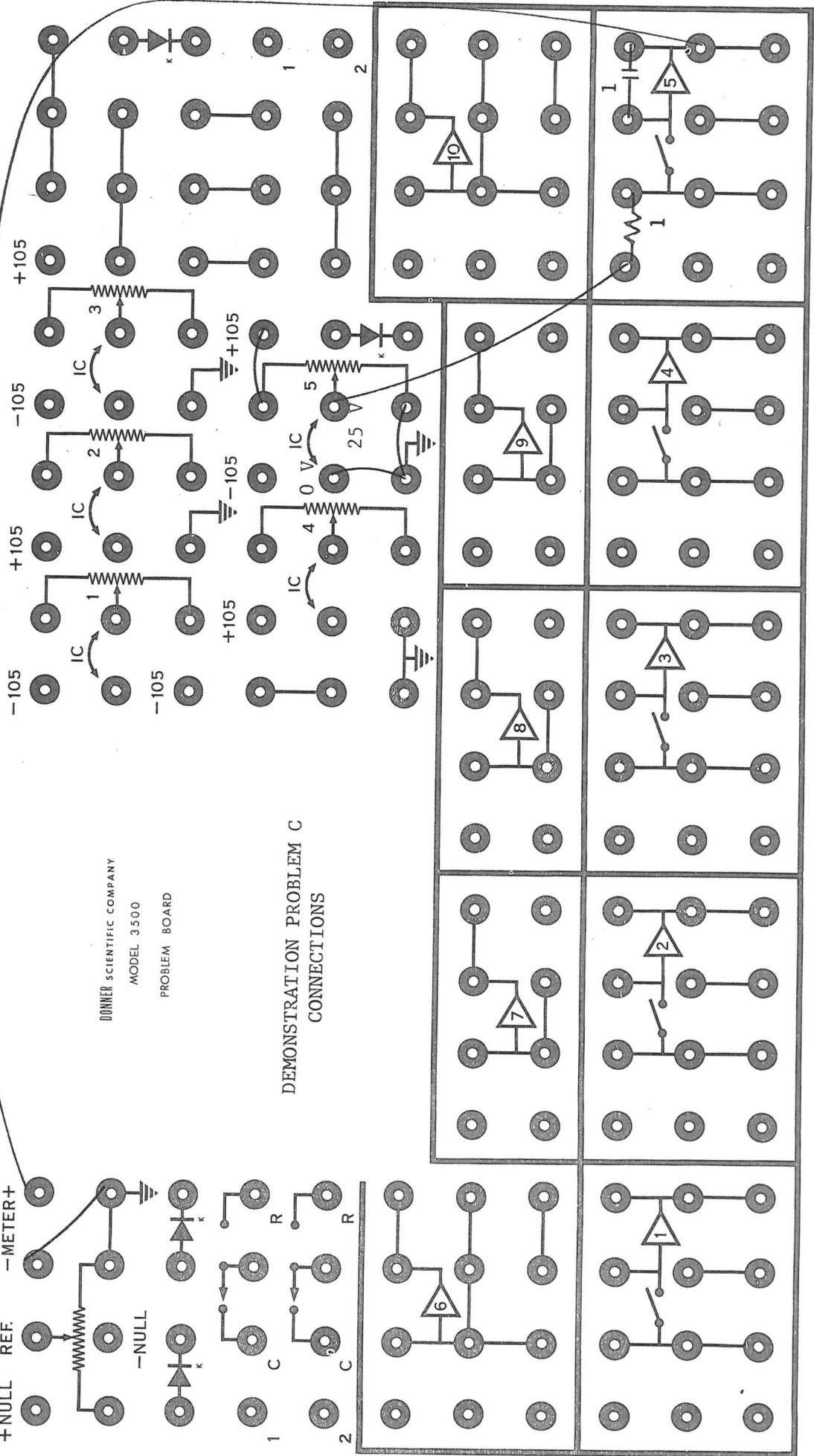


AUXILIARY
POTENTIOMETERS



DONNER SCIENTIFIC COMPANY
MODEL 3500
PROBLEM BOARD

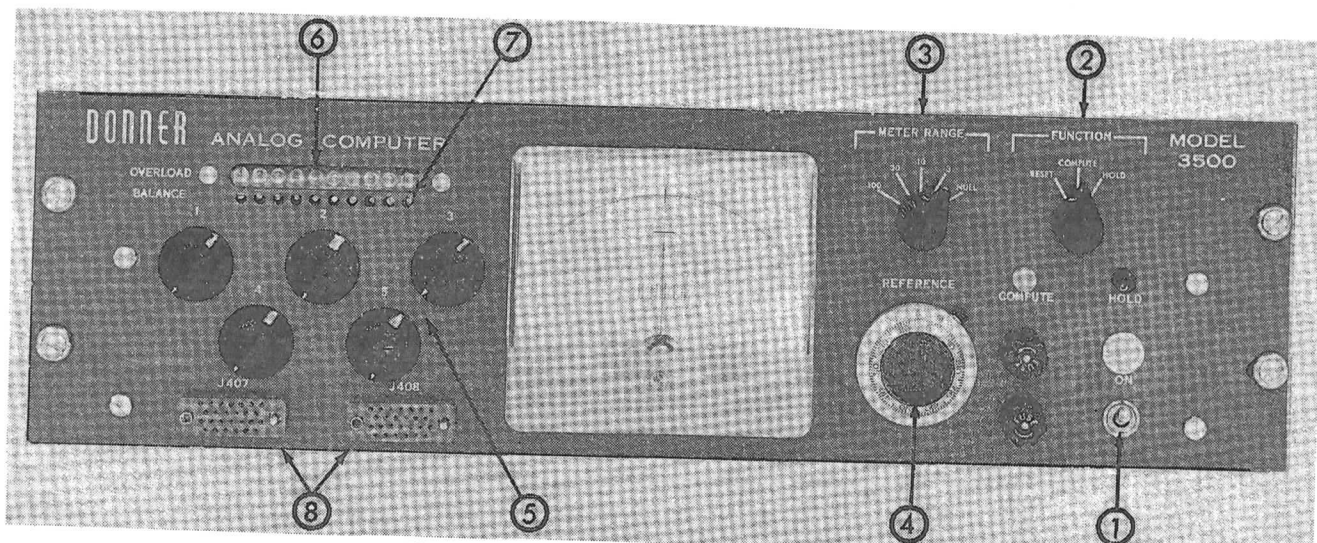
DEMONSTRATION PROBLEM C
CONNECTIONS



PROGRAMMING and OPERATION

1 - Operating Controls and Indicators

Figure 3



<u>Name or Panel Legend</u>	<u>Explanation</u>
① POWER (switch and "on" indicator)	Applies all operating power.
② FUNCTION RESET _____ COMPUTE _____ HOLD _____	Applies initial conditions preparatory to running the problem solution. Initiates the problem solution. Interrupts the problem solution, maintaining instantaneous values.
③ METER RANGE 100V, 30V, 10V, 3V _____ NULL _____	Direct-reading meter ranges. Null voltmeter (0.1 volt sensitivity).
④ REFERENCE _____	Calibrated dial which selects comparison voltage for null voltmeter.
⑤ POTENTIOMETERS _____	Used to select initial condition voltages for integrators and as coefficient potentiometers.
⑥ OVERLOAD _____	Each lamp lights up when output of corresponding amplifier exceeds 100 volts to indicate error in solution.
⑦ BALANCE _____	Screwdriver adjustment for balancing correspond-amplifier.
⑧ RECEPTABLES J407 & J408 _____	For connecting optional remote problem boards or for connecting amplifiers to external equipment.

2 - Preliminary Adjustments

2.1 Warm-Up

Turn on the panel power switch and allow the Model 3500 to warm up for at least ten minutes prior to making any of the adjustments described on succeeding pages. The amplifier overload indicators will light up when the computer is first turned on. Normally, they will extinguish after one minute. If an amplifier is unconnected, it will be necessary to plug-in a feedback resistor between the amplifier input and output terminals (see 4.2).

2.2 Balancing the Amplifiers

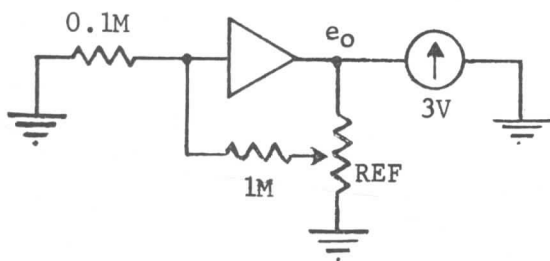
To perform correctly, each amplifier must be balanced so that when an input of zero volts is

applied, the output will also be virtually zero. The chopper-stabilized type amplifiers are highly stable and will seldom require a balance adjustment. They should be checked at weekly intervals, however, while the unstabilized amplifiers should be checked daily. Proceed as follows:

1. Connect each amplifier, in turn, as an inverter with a gain of 1000, if it is chopper-stabilized, or a gain of 100 if it is unstabilized. The reciprocal coefficient circuit (see II-6.2) is most convenient for obtaining these large gains. Use the REFERENCE potentiometer as shown below:

BALANCE CIRCUIT

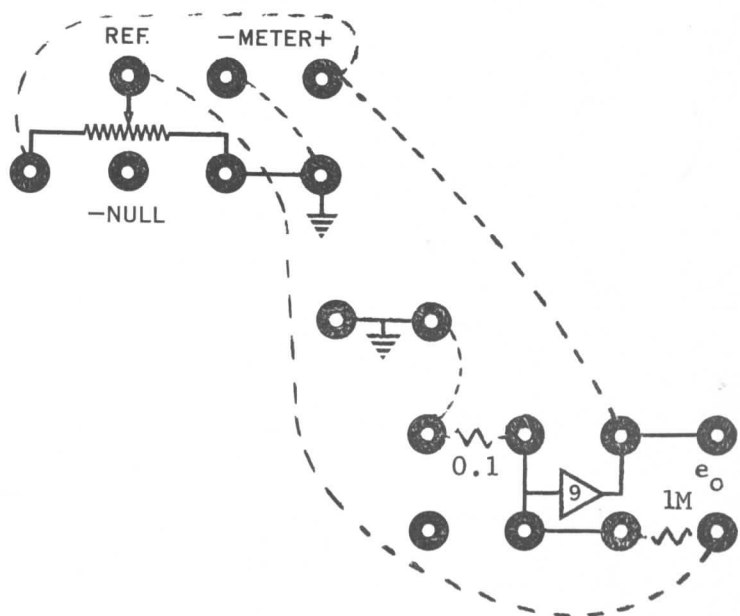
Circuit Diagram



For stabilized amplifiers, set the REFERENCE dial to .010 and for unstabilized amplifiers set the dial to 0.100 (see 3.2a).

2. Connect the meter to read the output voltage of the amplifier (see 3.1). Select the 3V meter range.
3. The meter reading should not exceed ± 0.4 volt for any amplifier, although it may vary within this limit*. If correction is necessary, turn the corresponding amplifier screwdriver BALANCE adjustment (on the front panel) until the average meter reading is zero. A small screwdriver is provided for this adjustment.

Problem Board Connections



* This error represents a typical offset at the amplifier summing junction of 400 microvolts for the stabilized amplifiers or 4 millivolts for the unstabilized amplifiers.

4. Remove the connections to the amplifier and then repeat these steps for all remaining amplifiers (or at least the ones which are to be used). When finished, return the METER RANGE switch to 100V.

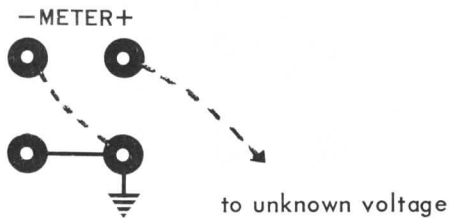
3 - Using the Panel Meter

The panel meter may be used either as a direct-reading meter for monitoring the outputs of amplifiers and for general measurements, or as a null voltmeter for measuring with 0.1% accuracy coefficient potentiometer settings, initial condition and other constant voltages in the computer and in external equipment.

CAUTION! Do not leave the meter in the NULL voltmeter function while running a problem solution or monitoring amplifier outputs. The meter may load the amplifiers, giving erroneous results.

3.1 To Use the Meter for Direct Voltage Readings

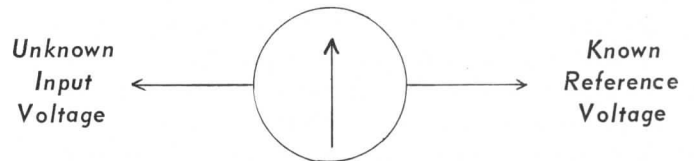
Set the METER RANGE switch to the desired scale. Normally, use the 100-volt range for all initial readings and then select the appropriate smaller scale. Connect the meter as follows:



A positive voltage is indicated on the meter by deflection to the right and a negative voltage by deflection to the left.

3.2 Null Voltmeter

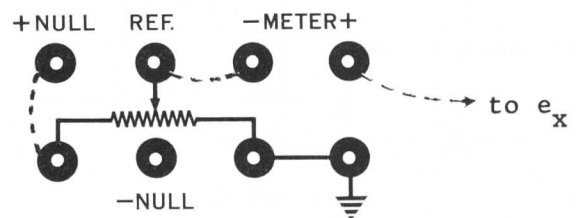
When the METER RANGE switch is set at the NULL voltmeter position, the meter compares the unknown input voltage with a known reference voltage selected by the REFERENCE knob. This may be represented as in the diagram below:



The REFERENCE potentiometer, when used in the NULL function, selects a meter reference voltage between 0 and ± 100 volts, accurate to the nearest 0.1 volt.


- a. **Reading the Dial:** Each revolution of the REFERENCE dial represents a ten-volt increment. To select a reference voltage of +54.6 volts, for example, turn the REFERENCE knob until "5" appears in the digit window and the pointer indicates "46" on the dial face. When measuring coefficient potentiometer settings (see 4.3b), the REFERENCE dial reading will be interpreted as the ratio of reference voltage (output at the REFERENCE POTENTIOMETER ARM) to 100 volts, (the full voltage across the REFERENCE potentiometer when connected). For instance, in the previous example, the reading of 5-46 will be interpreted as 54.6 V / 100V, or 0.546.

- b. **Null Voltmeter Connections:** The diagram below shows problem board connections for measuring a positive unknown voltage with the null voltmeter. (For coefficient potentiometer adjustments, refer to 4.3b). To measure a negative voltage, substitute the -NULL terminal for the +NULL terminal.



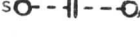


To measure the unknown fixed voltage e_x , adjust the REFERENCE knob until the meter indicates zero and then read the REFERENCE dial.

4.1 General

The computing circuit described by the final diagram is constructed on the problem board by interconnecting the various computing elements of the computer, all of which have terminations on the problem board. The arrangement and marking of the problem board allows construction of a physical circuit which closely resembles the prepared circuit diagram. All problem board terminals of computing elements are identified by their common symbols; for example, amplifiers ,

potentiometers , diodes .

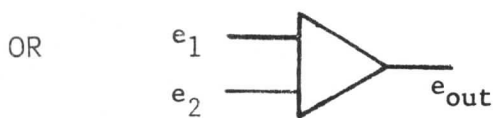
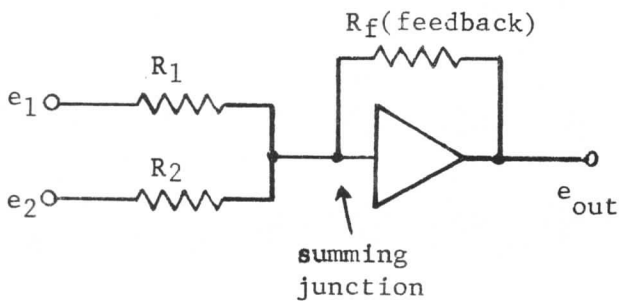
Auxiliary terminals such as METER, GROUND , and +100V are clearly labeled. In the illustrations in this section, dotted lines are used to indicate plug-in resistors , capacitors , and patchcords.

CAUTION!

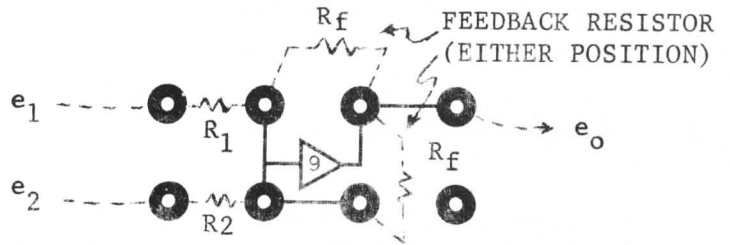
WHEN THE COMPUTER IS ON, APPROXIMATELY 100 VOLTS D.C. EXISTS AT THE 105V TERMINALS AND POSSIBLY AT MANY OTHER TERMINALS ON THE PROBLEM BOARD. BE CAREFUL NOT TO CONNECT THESE TERMINALS TO GROUND OR THE COMPUTER CHASSIS. ALSO, DO NOT TOUCH THE EXPOSED METAL TIPS OF THE PATCHCORDS.

4.2 Amplifier Terminals

a. **Summing Amplifiers:** There are two basic amplifier terminal configurations. The typical summing or inverting operational circuit is generally represented as:

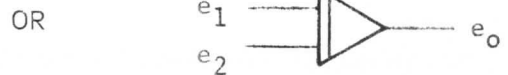
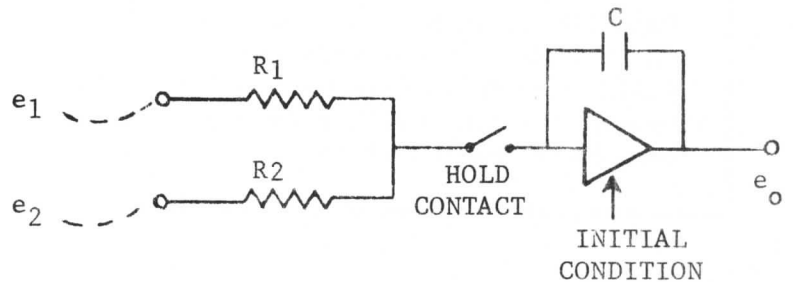


The terminals of amplifiers nos. 6 through 10 normally will be utilized as below:

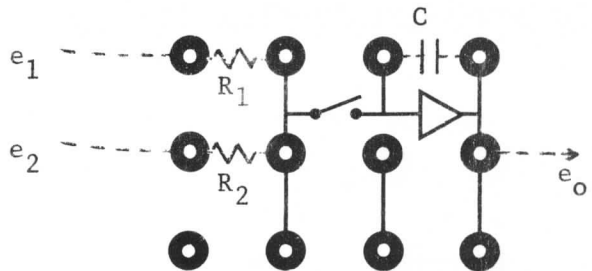


If additional inputs are needed, two or more plug-in components may be stacked at the same terminals. Amplifiers nos. 6 and 10 have extra input terminals.

b. **Integrator - Summing Amplifiers:** For the typical integrating circuit generally represented by:

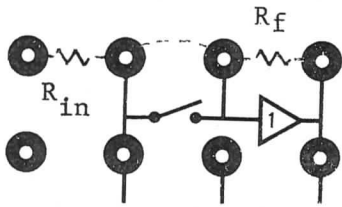


the terminals of amplifiers nos. 1 through 5 are normally utilized as below:



(Refer to Dwg. No. 3899 in the Appendix for the complete circuit diagram of an integrating amplifier.) The initial condition voltage source is obtained from the corresponding IC potentiometer in the upper-right portion of the problem board. (See 4.3a for connections and adjustments.)

Any of Amplifiers nos. 1 through 5 may also be used for normal summing and inverting (sign-changing) operations by inserting a patchcord across the "hold" contacts thus:

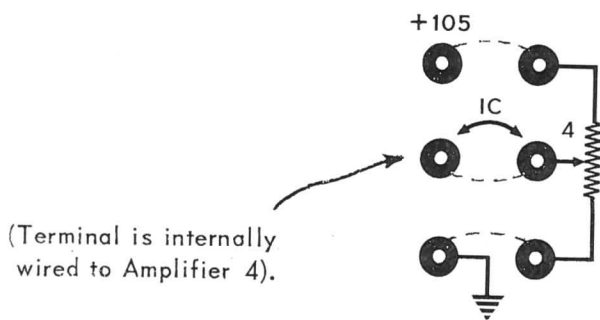


CAUTION: Be careful not to connect an amplifier output terminal to ground.

4.3 Potentiometers

The five potentiometers grouped on the front panel are used either to establish problem coefficients or as sources of constant input voltages or initial condition voltages for the corresponding integrator amplifiers. Normally, these potentiometers will be adjusted by means of the null voltmeter. In common practice, the potentiometers are patched into the computer circuit before being adjusted.

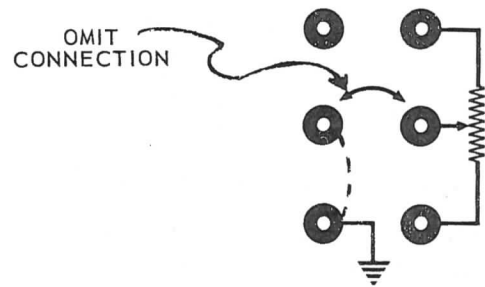
- a. **Initial Conditions:** For each integrator amplifier which requires an initial condition voltage other than zero, connect the correspondingly numbered "IC" potentiometer as shown below:



Connections for a Negative IC Voltage

IMPORTANT! Note that the top patchcord is connected to the +105 terminal to establish a **NEGATIVE** initial condition. (The initial condition is produced at the output of an amplifier which reverses the voltage polarity.)

If the initial condition voltage for a particular amplifier is to be zero volts, it is only necessary to "ground" the IC terminal adjacent to the potentiometer of corresponding number as shown:



Connection for Zero Initial Conditions

The potentiometer is then free for use as a coefficient "pot".

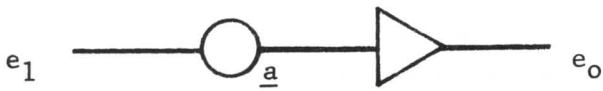
To Establish an Initial Condition Voltage

Let us assume that an initial condition of +60.0 volts is to be applied to integrator amplifier No. 4.

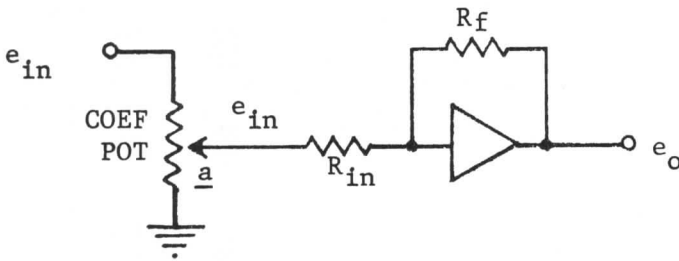
1. Place the FUNCTION switch at "Reset".
2. Connect potentiometer No. 4 for initial conditions as above but with its top terminal patched to the -105 (not +105) volt terminal.
3. Connect the null voltmeter as in par. 3.2b to measure a positive voltage. Set the REFERENCE dial at 60.0 ("6" in window, "00" on dial).
4. Connect the +METER terminal to one of the output terminals of amplifier No. 4.
5. Turn potentiometer No. 4 until the meter reads zero. The adjustment is now complete. Disconnect the meter.

(Note: Initial condition voltages may be adjusted within an accuracy of one to two volts by reading the amplifier output voltage on a direct-reading meter scale.)

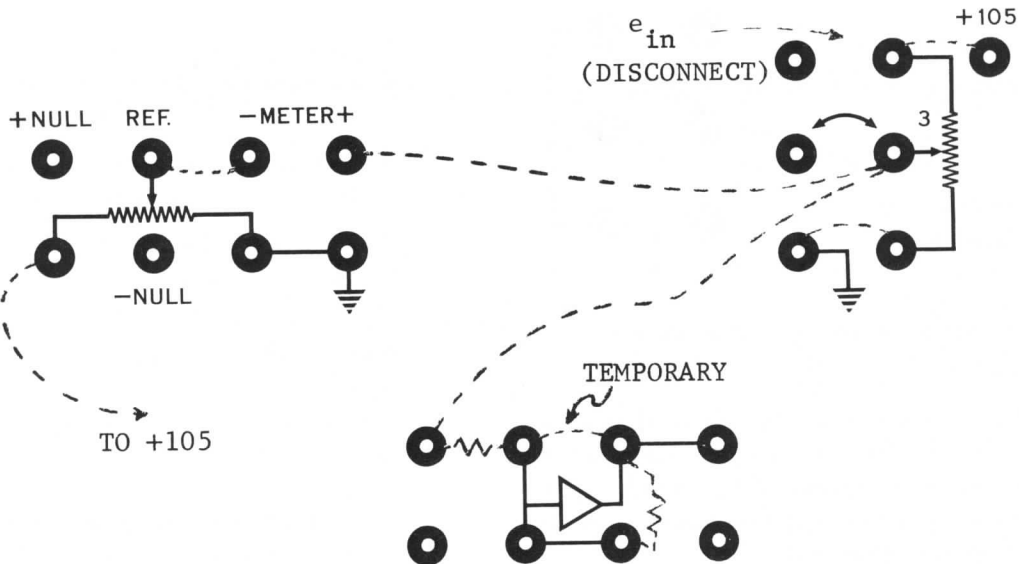
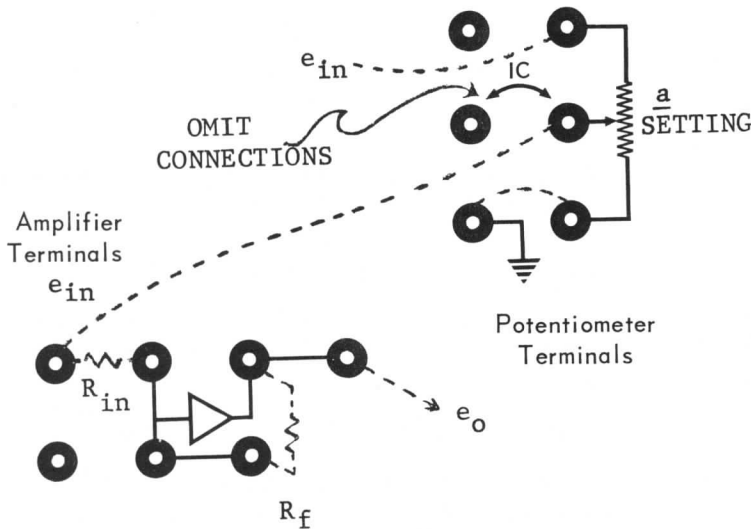
- b. **Coefficient Potentiometers.** Where a coefficient a is indicated in a problem diagram as:



in the computer circuit diagram it would be translated as:



where a is the setting of the potentiometer. Using any potentiometer not employed for initial conditions, make the following connections:



Connections During Adjustment of a Coefficient Potentiometer

To Adjust a Coefficient Potentiometer:

1. Place the FUNCTION switch at "Compute".
2. Connect a patchcord temporarily between the input and output terminals of all amplifiers associated with coefficient potentiometer as shown in the figure at the bottom of the page.
3. Temporarily connect the top terminal of the potentiometer to the +105 terminal only (for the sake of standardizing), at the same time removing the connection to e_{in} .
4. Interconnect the potentiometer and the null voltmeter as shown below.
5. Adjust the meter REFERENCE potentiometer for the desired setting.
6. Turn the coefficient potentiometer until the meter reads zero. The adjustment is now completed. Restore the original circuit connections as above, making sure that the temporary patchcord between the amplifier input-output terminals is removed.

- c. **Fixed Voltage Sources:** To obtain a fixed voltage (other than an initial condition), as for a constant amplifier input, use the same circuit connections shown for a coefficient potentiometer in par. 4.3b above, except use a +105 or -105 terminal (choose the same polarity as the desired voltage) for the source of e . The potentiometer adjustment procedure is also identical to that for coefficients, except the left terminal of the REFERENCE potentiometer must be connected to the same 105V polarity as the potentiometer.

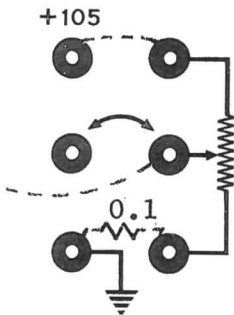
d. Using the Auxiliary Potentiometer Strips:

When the Model 3570 or 3571 potentiometer strip assembly is installed, its terminals are utilized in exactly the same manner as the terminals of the five potentiometers on the Model 3500 panel, except that the auxiliary potentiometers are not used to supply initial condition voltages to amplifiers nos. 1 to 5. Connect a patchcord between one of the ground terminals on the strip assembly and a ground terminal on the problem board. The potentiometer dials on the Model 3571 are read in the same manner as the Reference potentiometer.

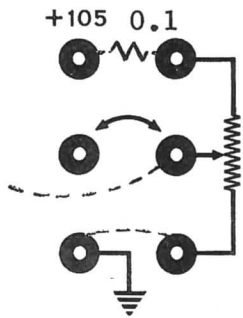
e. Suggestions on Adjusting Potentiometers:

1. Resolution of the potentiometers can be improved two-fold, thereby making their adjustment easier (less sensitive per degree of turning), by the following techniques:

A. If the desired voltage or coefficient is above mid-scale (50 volts or 0.500), insert a 0.1 megohm resistor as shown:



b. If the desired voltages is below mid-scale, insert a 0.1 megohm resistor as shown:



2. If the null voltmeter is not used, the REFERENCE potentiometer may be employed as an additional coefficient potentiometer. It may be adjusted readily by the direct-reading method given in par. 4.3b. In the Appendix you will find a load-compensation table for a calibrated 100K-ohm potentiometer, which is applicable to the REFERENCE potentiometer and the Model 3571 auxiliary potentiometer strip. This chart gives instructions for setting the dial correctly without voltage readings for several values of load (amplifier input) resistors.

e. **Individual Plug-in Potentiometers (Donner Stock No. 3961):** This component may be used to supplement the five panel-mounted potentiometers when the auxiliary potentiometer strip (Model 3570 or 3571) is not purchased. In general, it must be inserted in any two isolated terminal-jacks on the problem board. Connections and adjustments are made as described for coefficient potentiometers. The movable arm terminal of the potentiometer does not have a "through" terminal at the bottom.

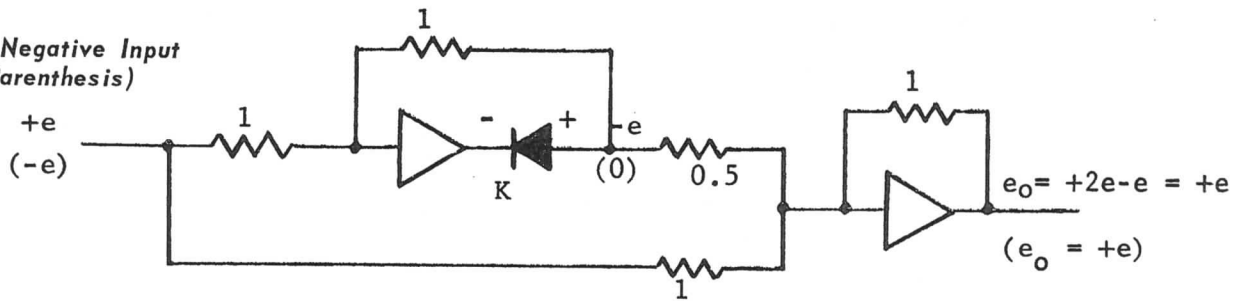
4.4 Miscellaneous Problem Board Terminals

a. **Diodes** : Four diodes are available for "back-lash" simulation, limiting, and function generator circuits as discussed in the accompanying computer theory manual. When the relative polarity of the applied voltage is thus:

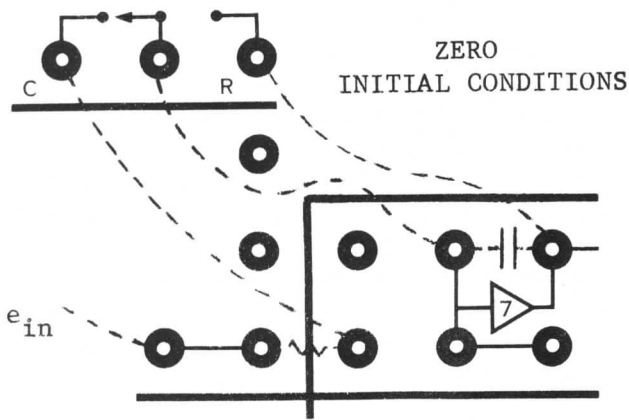
(+) (-) the diode is essentially a short circuit, allowing the signal to pass. When the relative polarity is reversed, the diode is an open circuit.

The "absolute value" circuit shown below illustrates a typical use. Because of the arrangement of diode and the inverting amplifier No. 1, the output voltage (e_o) will always have a negative value, regardless of the sign of the input voltage.

(Voltages For Negative Input shown in Parenthesis)



b. **Compute-Reset (R-C)**; These two sets of switch contacts may be used as double-throw switches to synchronize auxiliary circuitry with the "compute" and "reset" modes; thus, they may be used to "slave" a Donner Model 3400 Computer in the Compute and Reset modes. A special interconnecting cable will be provided on request. One may also convert two summing amplifiers (Nos. 6 thru 10) to integrating amplifiers with zero initial conditions according to the following circuit connections:



c. **Trunk Lines**: In both outside columns on the problem board are two sets of terminals labeled "1" and "2" which are interconnected to facilitate connections between widely separated terminals.

4.5 Operational Relays

An operational relay, Donner part no. 3965, is available as an accessory plug-in unit. It can perform many useful functions such as providing additional integrator logic and relay comparator amplifier circuitry. A full description with typical applications is given in a supplementary data sheet in the appendix.

5 - Problem Solution

After the problem board circuit connections have been completed and verified, and all coefficient potentiometer and initial condition voltages have been set, the problem is ready for solution. The solution is usually represented by variations

in voltage occurring at one or more points in the problem circuit which may be monitored on the direct-reading 100-volt meter scale or observed on an oscilloscope, or may be plotted by a pen recorder connected to the output point; or it may be the fixed voltage existing at one or more points in the circuit after a precise time-interval of integration. All variables may be plotted simultaneously with a multi-channel recorder.

To run the solution, first turn the FUNCTION switch to "RESET" for a brief moment to re-establish initial condition voltages throughout the circuit. Then place the switch at "COMPUTE". All circuit connections are now automatically completed and the computer "solves" the problem programmed on the problem board. Frequently, the solution is run for a given interval of time corresponding to real or scaled time. At the end of the computing period, turn the FUNCTION switch to "HOLD". If it is desired to continue the solution from the point of interruption, return the switch to "COMPUTE" without first switching to "RESET". To repeat the solution from the initial conditions, return the FUNCTION switch to "RESET" for a brief moment, and then to "COMPUTE".

6 - Amplifier Overloads

The overload indicators on the panel light up when the output voltage of their corresponding amplifiers exceeds ± 100 volts. All problems should be scaled, according to the instructions in the computer theory manual, for a maximum output swing of ± 100 volts. If an amplifier overloads during operation, place the computer in "HOLD" and then:

1. Verify the magnitude scaling of the problem by measuring the amplitude of input voltages (usually at the outputs of the preceding amplifiers) to be sure that they remain within the predicted range;
2. Look for errors in connections and values of computing components;
3. Re-examine initial condition voltages;
4. Finally, check amplifier balance.

CIRCUIT DESCRIPTION

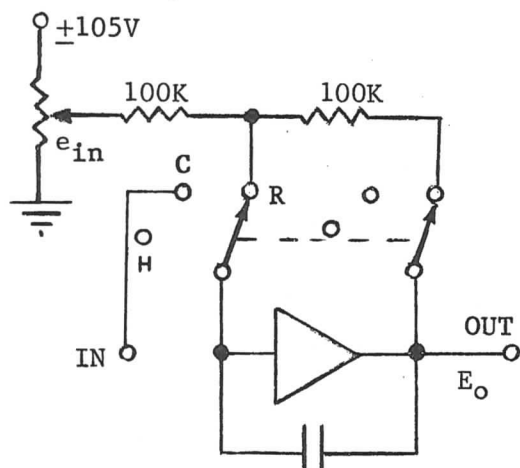
All components of the M3500 computer are represented on schematic diagram No. 3899.

1. Balance Circuitry

The arm terminal of the amplifier zero adjust (balance potentiometers R420-1 thru R420-10) are permanently wired to the balance voltage pin of the corresponding amplifier receptacle connector (at pin D or F of J401 through J405). The voltage obtained at the arm of each potentiometer supplies the necessary bias for zero-volts output when the amplifier input is also zero. (Refer to the Model 3103 Amplifier manual in the appendix.)

2. Initial Conditions

When an amplifier is connected as an integrator, and the initial condition voltage is applied with the function switch at "reset", the equivalent circuit is as shown in the illustration below.



In effect, the amplifier is a summing type since the capacitor is fully charged before "compute". E_o is the initial condition voltage and is determined by the level of e_{in} . Note that the initial condition voltage is always opposite in polarity to the input bias voltage. The I.C. network is removed when the function switch is placed at "compute", but the I.C. voltage is maintained by the charge on the capacitor.

3. Hold

When the function switch is placed at "hold", all input connections to integrating amplifiers are simultaneously disconnected. Whatever charge is on the plug-in feedback capacitor remains since

no discharge path exists. Thus, when the function switch is returned to "compute", the problem solution will resume with the same values as at the moment of interruption.

4. Voltage Supplies

The positive and negative 105-volt voltage supplies used for initial conditions and other voltages are obtained from the constant 105 volt potential across the type OB2 gas reference voltage tubes, both driven by the +300V and -150V regulated power supply voltage. R417 and R418 function as limiting and dropping resistors.

5. Overload Circuit

The overload indicators in the Model 3500 are a simple voltage type. An NE-2 neon lamp ignites when the voltage across R405 reaches approximately ± 70 volts, corresponding to a total amplifier output voltage of $\pm 100V$.

6. Meter Circuit

The meter is protected from burn-out in all modes by fuse F403. The four direct-reading ranges (3V, 10V, 30V, and 100V) are calibrated by 1% resistors (R408 through R411) in series with the 100-microampere meter movement M401. The type 1N138A limiting diodes (CR401 and CR402) provide a shunt path around the meter movement when full scale current is exceeded.

In the Null voltmeter function, the meter indicates the difference of potential between the reference voltage applied to one meter terminal and the unknown voltage applied to the other. When both voltages are equal, no current flows through the meter which therefore indicates zero and, consequently, no load current is drawn from the reference voltage supply. The two type 1N295 diodes (CR403 and CR404) protect the meter from overload condition when operated as a null meter.

The reference voltage available at either NULL terminal is equal to $\pm 100V$ only when the REFERENCE potentiometer is connected between the terminal and ground, providing a constant 100K load resistance in addition to the resistance of R412 and R413 (or R414 and R415). Connecting any other load to the terminal (for example, the panel meter on a direct-reading scale) will change the value of voltage at the NULL terminal.

SERVICING

1. Disassembly

The components of the Model 3500 computer are accessible for servicing by unlocking the two wing-screws on the rear apron and lowering the apron. The five amplifiers and the voltage regulator card may be pulled directly out of their receptacle connectors. The computer may be disassembled further as indicated in Figure 4 with the removal of a few screws. After replacing the circuit cards be sure that they line up in the grooves of the rubber guide inside the rear apron before locking the apron.

2. Routine Checks and Adjustments

The only adjustments on the Model 3500 are the two NULL voltage controls accessible through holes in the rear apron and the two regulated output voltage adjustments on the voltage regulator card. Under normal conditions, the power supply voltages can be expected to remain within specified tolerances for many months, although small changes caused by tube aging is normal.

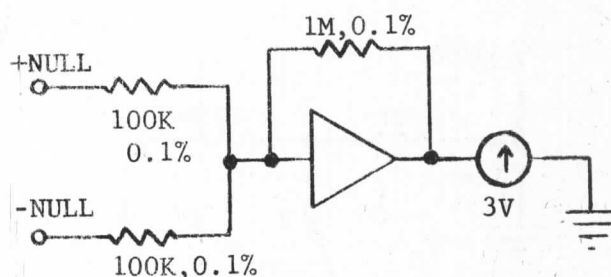
A daily or weekly check should be made of the +300V and -150V power supply output voltages. A quick method is to connect the Reference Potentiometer between one NULL terminal and ground for proper loading and read the voltage at the same NULL terminal with the 100V scale of the panel meter. Normally, it will measure $93V \pm 4\%$ because of the additional loading effect of the meter.

Every few months, or when a change is noted in the daily or weekly voltage check, a more precise measurement should be made. Direct readings of the NULL voltages can be made with a differential type voltmeter of at least 0.1% accuracy. Both positive and negative readings should be within 0.1% of 100V and should track within 0.1% of each other when the +300V regulated output voltage is intentionally changed by 1 volt. Correct indications at the NULL terminals reflect correct +300V and -150V regulated power supply voltages.

If the foregoing readings made with the differential voltmeter are out of tolerance, the regulated DC power supply voltages should be measured and set within 3% of their nominal

value, as described in the Power Supply and Voltage Regulator section. Afterwards, remeasure the NULL voltage levels at the problem board and, using the external precision differential voltmeter as reference, adjust first the +NULL and the -NULL controls at the rear for the correct level. Although it is desirable to set these voltages as near to a true 100 volts as possible, the equality between +NULL and -NULL is of greater importance than the absolute value, especially when the Model 3500 is not being used with other equipment containing an internal reference voltage.

If a precision external differential voltmeter is not available, measure the +300V and -150V outputs with the best available meter and then measure the equality of the +100V and -100V outputs at the NULL terminals by the null-indication circuit shown below:



Read the error voltage on the 3-volt scale of the panel meter. An allowable one-volt deflection indicates an actual deviation of 0.1 volt. Reverse the +NULL and -NULL terminal connections and read the voltage again. The deviation from zero in both cases should be equal but opposite in polarity. Adjust the -NULL screwdriver adjustment for the correct indication. To readjust both the +100V and -100V levels, an external reference voltage is necessary.

3. Trouble-Shooting

When trouble occurs during operation with the Model 3500, it is suggested to go over the operating procedure to make certain that no errors have been committed. If this does not prove to be the fault, make the following tests, as applicable, to help localize the source of trouble.

1. If a faulty amplifier is suspected, replace the card with another which appears to be operating normally. The following simple test will also help determine normal functioning of the amplifier. Connect the amplifier as a summer with 1 megohm input and feedback resistors. Apply successive inputs of, for example, 0 volts, $\pm 10V$, $\pm 50V$, $\pm 80V$, and $\pm 100V$. Use a coefficient potentiometer connected to a +105V terminal as the voltage source and measure both input and output voltages with the appropriate scale of the panel meter. They should be equal ($\pm 1\%$).
2. Measure the voltage at the +NULL and -NULL terminals, using the panel meter with the REFERENCE potentiometer connected between the terminal being checked and ground, to determine the presence of regulated power supply voltages. A normal indication is $93V \pm 4\%$. If the voltage is not present or is incorrect, refer to the Power Supply and Voltage Regulator section.
3. Measure the voltage at the +105 and -105 terminals. The panel meter in the 100V range will give a sufficiently accurate indication and will not be harmed by the overload.
4. Check the meter operation by measuring a voltage at the problem board with an external meter. If the meter operates in the direct reading ranges but not in "null", check fuse F403.
5. Do not overlook the possibility of a defective patchcord, plug-in resistor, or capacitor.

3.1 Amplifier Balance

If a particular amplifier will not balance as described in III 2.2, first replace it with another amplifier card. If the trouble remains, measure the balance voltage at pin D (for even-numbered amplifiers) or pin F (for odd-numbered) of the blue-ribbon connectors. Refer to Figure 4 for orientation. Use the panel meter in the 10-volt range. Turn the corresponding amplifier balance screwdriver control on the front panel in both directions to verify that the balance voltage has a range of at least ± 10 volts.

3.2 Integrator and Initial Condition Circuitry

If any abnormality is noted while setting initial conditions or in integrator operation, the only probable cause, besides amplifier malfunction, would be the switch terminals. Examine the switch for unusual signs such as dirty, burned or bent contacts, broken or shorted wiring, etc. The contacts may be cleaned with a piece of crocus cloth.

To check the initial condition potentiometer, substitute another one at the I.C. jumper terminal corresponding to the amplifier in question. If the initial condition voltage is of the wrong polarity, remember that the bias voltage connected to the top terminal of the I.C. potentiometer must be opposite to the desired output polarity.

3.3 Errors

Abnormal errors in computation may be caused by defective amplifiers which exhibit low gain and excessive drift. Poor performance of the voltage regulator is another possible cause. Tube replacement will commonly restore the amplifiers and voltage regulator to normal operation.

Further trouble-shooting procedures are given in the supplementary amplifier and power supply manuals.

PARTS LIST

NOTE: All fixed resistors are described on schematic diagrams.
deposited carbon type.)

Detail No.	Description	Mfr. - Part No.	Donner Stock No.
C401, C402 C403	Capacitor, 0.01 mfd +80% 300V cerm disc -20%	Electra Mfg. Co.	C0319
CR401, CR402 CR403, CR404 CR405 thru CR408	Dial, 15 turn Diode, 1N138A Diode, 1N295 Diode, HB6	Helipot Model RB Duodial Hoffman Raytheon Hoffman	CR0026 CR0008 CR0069
F401, F402 F401, F402 (alternate) I401-1 thru I401-10 I402	Fan, muffin "Venturi" Fuse, 3 A.G., 3 amp, 250 V Fuse, 3 A.G., 1½ amp (alternate for 230V operation) Glow lamp, neon	Rotron Mfg. Co. Littelfuse 312003 Littelfuse 31201.5	H-0263 F0010 F0011
I403	Indicator, neon, red	General Electric NE-2	I0009
I404	Indicator, neon, clear	Eldema 'E-lite' type 1B9-4779	I0018
J401 thru J406	Indicator, neon Connector, 15 pin	Eldema 'E-lite' type 1B9-4772	I0017
J407, J408 M401	Connector, 26 pin w/type G pins Meter, 100ua-0-100ua	Industrial Devices 1010A4 Amphenol 143-015-01	I0019 J0069
R401-1 thru R401-5 R406-R411	Potentiometer, 100 K, 2 W, 10% linear 1% dep. carbon resistors (refer to Schematic)	Winchester MRE 269-G Donner per Donner Dwg 100	J0125 15-3253 R0408
R412 R416 R417	Resistor, 45 K ½ W, 1% metal film Potentiometer, 100 K, 5W, 5%, 10 turns 0.1% linearity Resistor, 10 K, 10 W, 10% wirewound axial lead	Electra MF½-T1 Helipot series A, Model A	R0709 R0692
		Ohmite	R0689

Detail No.	Description	Mfr. - Part No.	Donner Stock No.
R420-1 thru R420-10	Potentiometer, 100 K	Bourns 'Trimit' 274-1-104	R0631
R425	Resistor, 1 K, 20 W 10% wirewound	Ward-Leonard Stripohm #305	R0753
R426, R427	Resistor, 1 K, $\frac{1}{2}$ W 1%	Ward-Leonard Stripohm type 30S	R0003
R428	Resistor, 750 ohm 30W 10% wirewound	Ward-Leonard Stripohm	R0752
S401	Switch, rotary 2 section 5 position (special)	Oak Manufacturing Co.	22-3916
S402	Switch, rotary, 3 section 3 position (special)	Oak Manufacturing Co.	22-3915
S403	Switch, DPST	Cutler-Hammer 8360-K8	S0009
V401, V402	Regulator, vacuum tube type OB2	R. C. A.	V0050

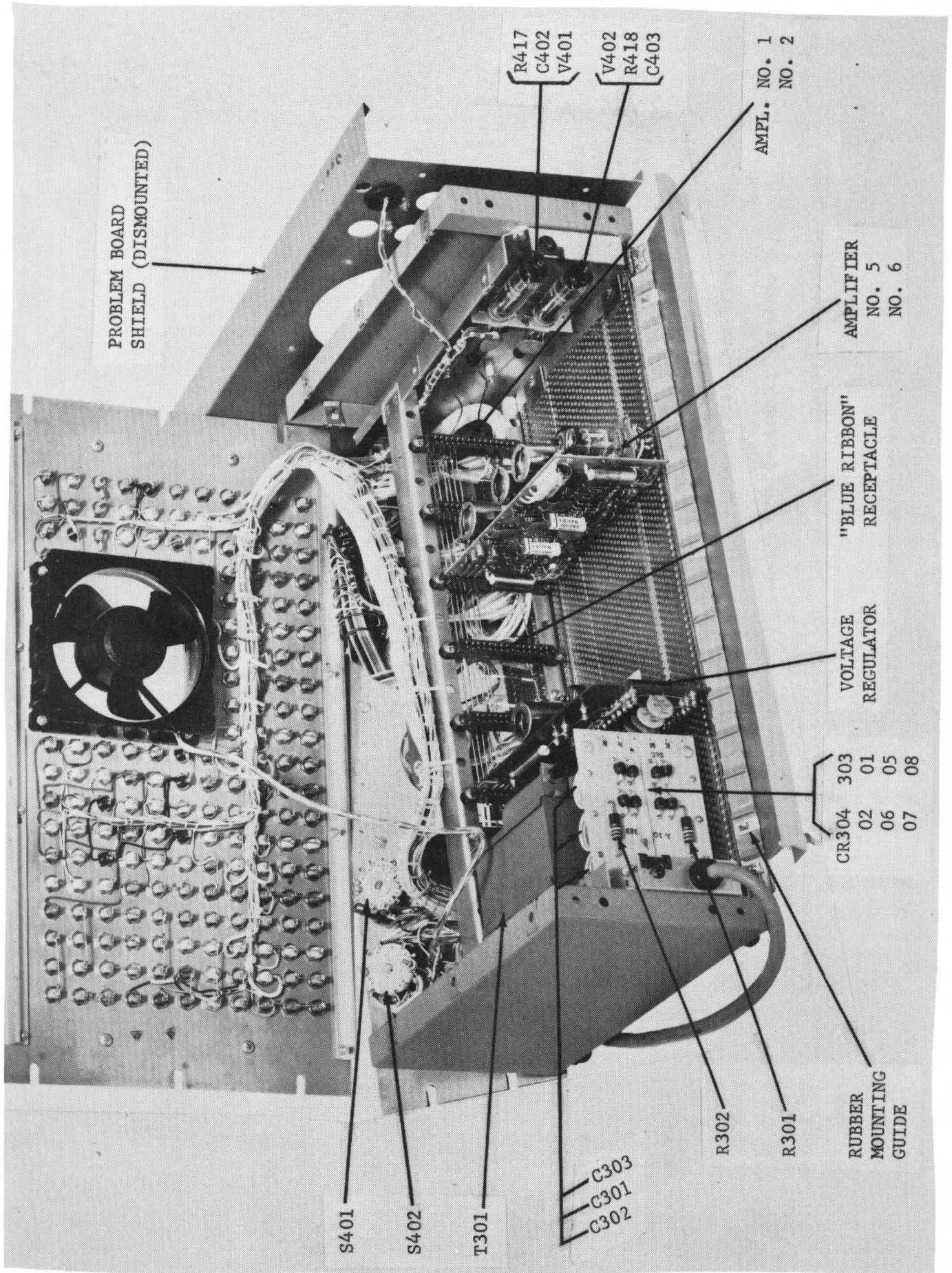


Figure 4 - Model 3500 Disassembled

GENERAL DESCRIPTION

The Power Supply, Donner Part No. 3901 and Voltage Regulator, Part No. 3902 are standard components of the Model 3500 Portable Analog Computer, and Model 3121 Amplifier Receptacle Unit. Together, they supply all operating power for the Model 3103 Dual DC Amplifiers used in these instruments as well as other operating voltages.

The Power Supply consists of a heavy duty transformer and attached component mounting board which are permanently mounted in the main instrument. It supplies an output voltage of +420 volts at 200 milliamperes and a negative output of -310 volts at 200 milliamperes. As with all standard instruments, the Power Supply is furnished to operate from either a 115V or 230V, 50-60 cps source, as ordered. Separate filament power of 6.3 volts A.C. is supplied to the amplifiers and the voltage regulator. All components in the basic Power Supply

circuit are accessible on the phenolic component mounting board when the rear apron of the instrument is unlatched.

The voltage Regulator is contained on a printed circuit card which plugs into a "blue ribbon" receptacle in the instrument mounting chassis adjacent to the Power Supply. This circuit utilizes the Power Supply outputs to produce an output voltage of +300V, regulated to 0.2% and -150V, regulated to 0.1% for amplifier operation. Each regulated output is controlled by a separate circuit within the regulator card. The +300 volt output uses a type 5651 tube as a prime reference, while the -150 volts is dependent on the +300 volt output for regulation. Each regulated output has a corresponding trim-pot located at the rear of the regulator card. The lower component adjusts the -150 volt output level and the upper component adjusts the +300 volt output level.

SPECIFICATIONS

POWER SUPPLY

Input Power (two versions):
115V, 50-60 cps at 1.7 amperes
230V, 50-60 cps at .85 amperes

Unregulated Output:
+420V at 200 milliamperes
-310V at 200 milliamperes
6.3V A.C. at 3.1 amperes
6.3V A.C. at 10 amperes

VOLTAGE REGULATOR

Output voltages
+300V $\pm 3\%$ at 100 ma
-150V $\pm 3\%$ at 25 ma

Regulation for $\pm 10\%$ line voltage or
or full load change
+300V : 0.2%
-150V : 0.1%

Stability:
8-hour, approximately 0.1%

Power Supply Section:

+420 volt and -310 volt outputs are obtained from a single tapped secondary winding of the power transformer. Both are produced by a full-wave bridge rectifier circuit employing silicon diodes. The +420V has a 2-pi output filter and the -310V has a single pi output filter. The filament voltage supplied to the regulator tubes (from the yellow transformer leads to terminals J & K of the blue ribbon receptacle) is biased at +100 volts by the external divider network consisting of the 110K and 220K resistor. The filament voltage supplied to the amplifier cards and V205 of the regulator section is effectively center-tapped by an external divider network consisting of two 1K, 1%, resistors.

Voltage Regulator;

The +300 volt output is regulated by two parallel type 7044 series-control tubes (V201 and V202). The grids of these tubes are, in turn, controlled by a two-stage amplifier, V203. A type 5651 tube (V206) provides the prime reference for the +300V output by maintaining the input grid of the V203 at a fixed +85V reference level. The regulating error-voltage is obtained from across the precision divider network consisting of R222 through R224, and is supplied to the cathode (pin 8 of V203). Normally, this cathode voltage is at essentially the same level as the grid voltage. When the +300V output voltage level tends to change, the cathode voltage changes proportionally, and thereby generates a signal which is amplified through V203 and applied degeneratively to the grids of the type 7044 tubes.

The -150V output is regulated in a similar manner by the cathode follower, shunt-control tube, V205. The grid of this tube is controlled by V204 which is a two-stage DC amplifier using the regulated +300V as its reference input voltage across the precision divider network consisting of R225, R230, and R231.

Introduction

The Power Supply and Regulator card are accessible for servicing by unlatching the rear apron of the instrument. Care should be taken when closing the apron again that the regulator and amplifier cards are properly aligned in the rubber mounting guide on the apron.

Adjustments

There are only two adjustments in the Power Supply and Voltage Regulator circuitry. R223 is the upper miniature trim-pot located at the rear of the regulator card and is adjusted first to provide the desired output level at terminal P of the "blue ribbon" receptacle of +300 volts $\pm 3\%$. Next, the lower trim-pot, R230, is adjusted for a level of -150 volts $\pm 3\%$ measured at terminal "M" of the blue-ribbon connector. Both adjustments should be made under half load conditions with the line voltage at 115V.

Performance Tests and Trouble-Shooting

The following tests will confirm the correct operation of the Power Supply and Regulator circuit.

A. Output Voltage:

Measure the regulated output voltage at terminals "M" and "P" of the blue-ribbon receptacle and adjust according to the "adjustment" procedure given above, if necessary. If the proper voltage level cannot be obtained, remove the regulator card from the instrument and measure the unregulated output at terminals "A" and "F" of the blue-ribbon receptacle. These should read approximately +420V and -310V respectfully.

If the correct DC output levels are not present, measure the AC output levels at the transformer secondary terminals at the component board. The AC voltage between the two terminals connected to the red transformer leads should measure 600V (r.m.s.) and the AC voltage at the two terminals connected to the orange leads should measure 450V (r.m.s.). If these readings are satisfactory, then diodes CR301 through CR308, resistor R301 and R302 and capacitor C301 to C303 must be checked. The diodes can be checked with power turned off by measuring the resistance across each pair (CR301 & CR302 and CR303 & CR304, etc.) in both directions. In one direction the value should be very large. In the opposite direction, the reading should indicate practically a short circuit.

SERVICING

Regulator Section:

If the output voltages of the Power Supply Section measured at terminals A & F are correct, proceed with tests in the regulator section as follows:

If no output voltage is obtained, check the filaments of the tubes in the regulator section. If low output voltages are measured at terminals M or P, replace the tubes in the regulator card. Replacement of tubes normally will correct malfunction in approximately 95% of the cases.

B. Regulation:

Under normal conditions, the output at terminals M and P will remain within their given specifications after an initial 15 minute warm-up period under conditions of $\pm 10\%$ line voltage change or zero to full load change. This characteristic may be readily tested if a variable line voltage trans-

former is available. Measure the regulated output voltages while changing the input line voltage level between 105 and 125 volts AC (or 205 and 250 volts AC). Drift characteristics of the voltage regulator section cannot be readily determined in the field unless a source of regulated line voltage is available and a highly stable precision voltmeter. For each of these cases, poor function of the regulator section as determined by the output voltage measurements will normally be caused by weak tubes.

The correct voltage across the type 5651 tube is an important factor. It can be measured at terminal "D" of the blue-ribbon connector and should have a value of 85 volts. The loss of regulation possibly caused by an open 1% resistor in the precision divider networks.

Typical voltage levels within the regulator circuit are given in the table below. Measured values should agree within $\pm 10\%$ of those given.

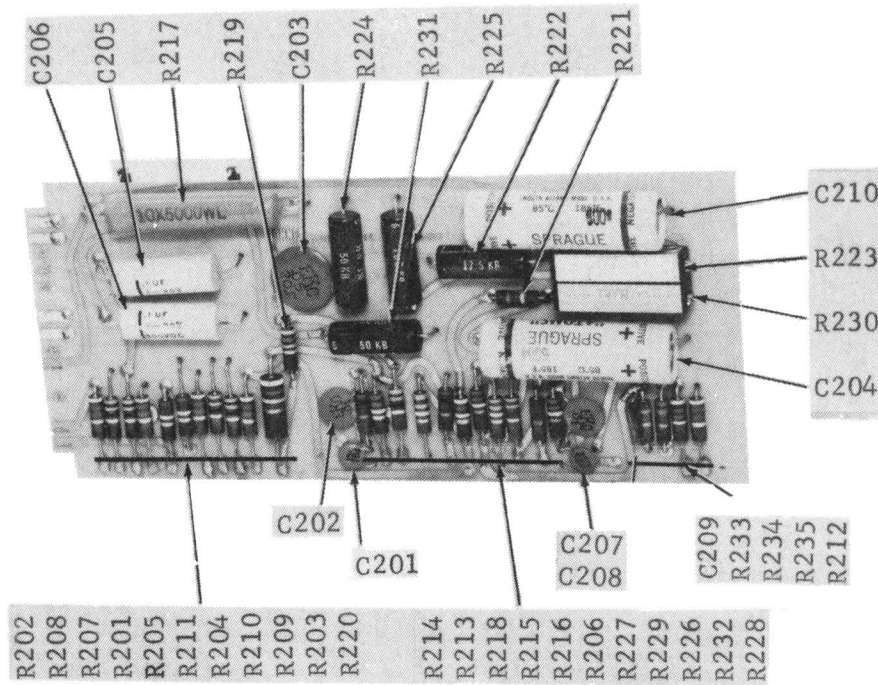
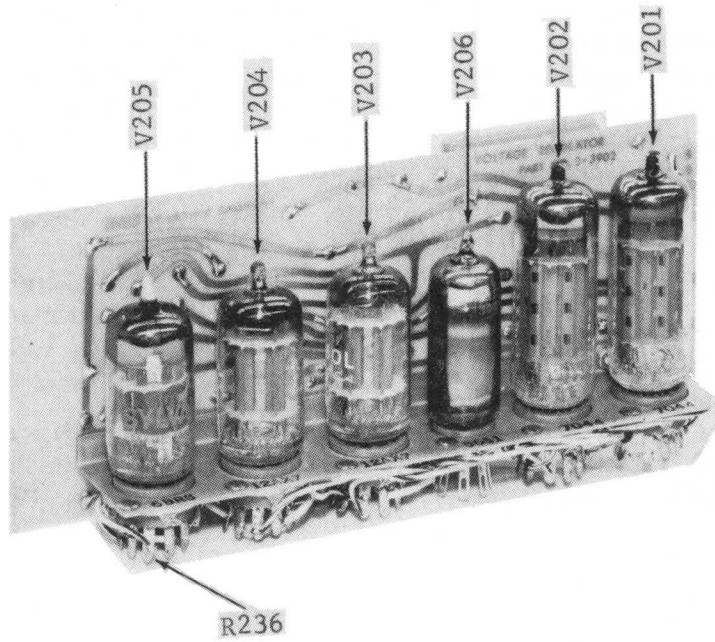
D. C. TUBE PIN VOLTAGES IN VOLTAGE REGULATOR

Tube	Pin: 1	2	3	4	5	6	7	8	9
V201 } V202 }	298	298	300			300	298		298
V203	300	-4	0			138	84	6	
V204	42	0	0.4			64	-0.6	0	
V205	-150	-2.5	-150			-2.5		-150	-150
V206	85	0							

Note: Voltages were measured with a Vtvm equivalent to Hewlett-Packard Model 410B.

PARTS LOCATION

VOLTAGE REGULATOR (2 VIEWS)



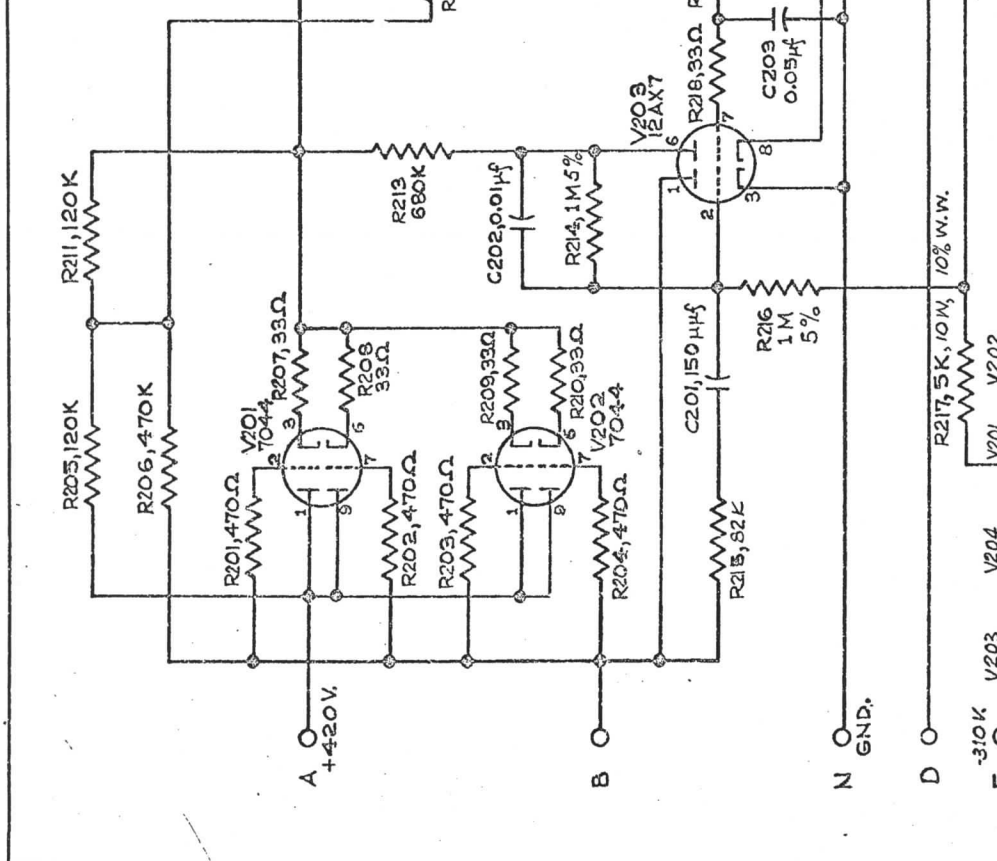
PARTS LIST

(NOTE: All common fixed resistors are described on schematic diagrams.)

Detail No.	Description	Mfr. - Part No.	Donner Stock No.
C201, C208	Capacitor, 150 mmfd	Mallory RMC Discs	C0320
C202, C207	Capacitor, 0.01 mfd 300V +80%, ceramic disc	Mallory RMC Discs	C0319
C209	-20%		
C203	Capacitor, 0.05 mfd 250V +20% cerm disc	Electra EKC 20X503MA2.5	C0255
C204, C210	Capacitor, 4 mfd 350V electrolytic	Spargue TVA 1601 1.8"x6" dia. max.	C0316
C205, C206	Capacitor, 0.10 mfd 300V	G. E. 61F31CB104	C0317
C301, C302	Capacitor, 20 mfd 500V electrolytic tubular	Spargue TVA-1906	C0315
C303	2.3" x 1.07" dia. max.		
CR301, CR302	Rectifier, silicone	Sarkes Tarzan F-6	CR0063
CR305, CR306			
CR303, CR304	Rectifier, silicone	Diode Inc. DI-58	CR0078
CR307, CR308			
R217	Resistor, 5K, 10 W 10% axial lead, wirewound	Lectrohm	R0680
R222	Resistor, 17.5 K 1W 1% metal film, 85°C.	Vamister 9852	R0683
R223	TC = 50 P.P.M. 1°C.		
R224	Potentiometer, 5 K, trim-pot	Bournes 275-1-502	R0686
R225	Resistor, 50 K, 2 W 1% metal film 85°C, TC = P.P.M. 1°C.	Vamister 9852	R0682
R230	Resistor, 100K, 2 W, 1% metal film 85°C, TC=50 P.P.M./°C.	Vamister 9852	R0681
R231	Potentiometer, 10K, trim-pot	Bournes 275-1-103	R0685
T301	Resistor, 50K, 1W, 1% metal film 85°C, TC = 50 P.P.M. /°C.	Vamister 9852	R0684
V201, V202	Transformer	PAECO 7893	23-3889
V203, V204	Vacuum Tube, 7044	Raytheon	V0073
V205	Vacuum Tube, 12AX7	Telefunken	V0071
V206	Vacuum Tube, 6BR8	Sylvania	V0074
	Vacuum Tube, 5651 Voltage Regulating	R. C. A.	V0006

REVISES	ECO NO.	ISSUE	DATE	APP.
SEE ECO	1251	B	5-1-61	MD

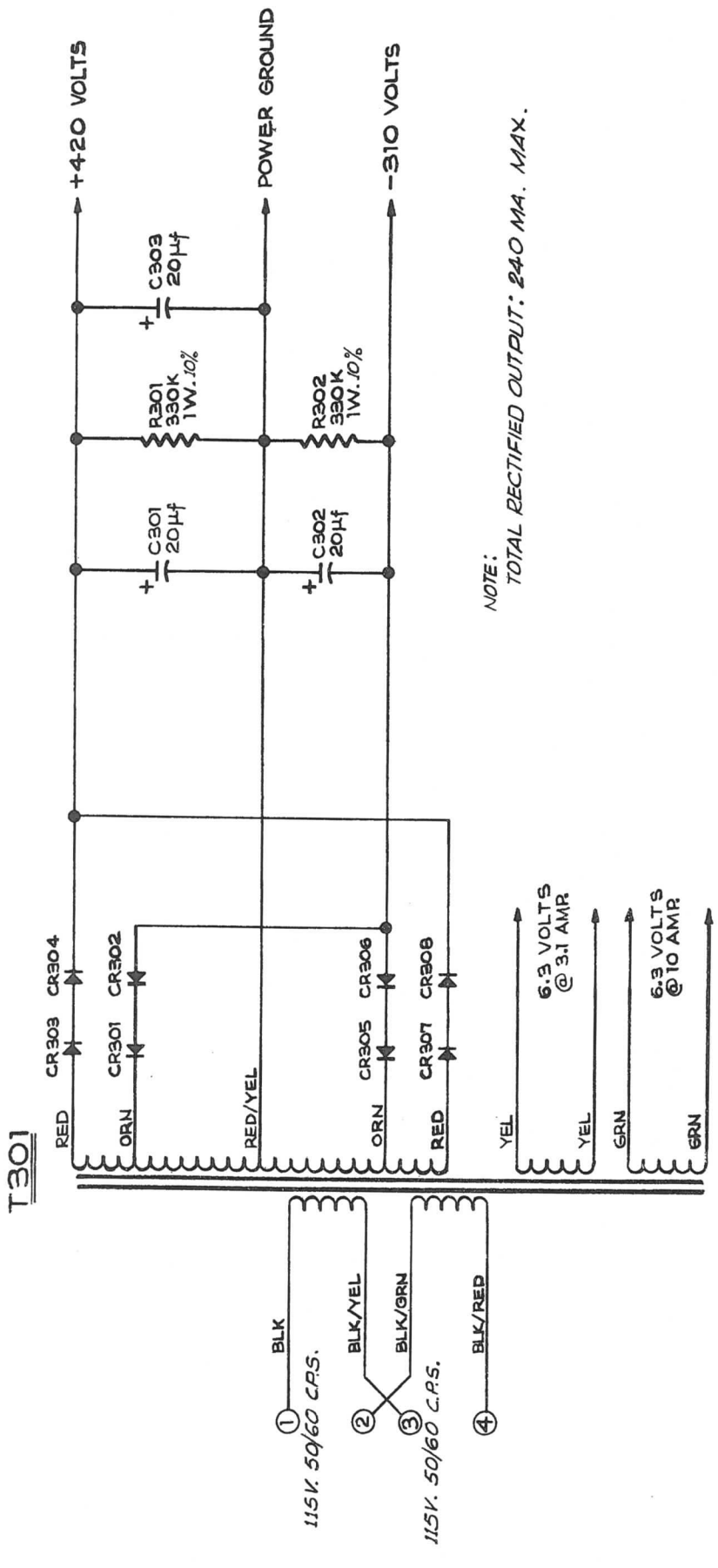
- S 6.3 V.A.C.
- R 6.3 V.A.C.
- P +300 V. REGULATED OUTPUT
- N PWR. GND.
- M -150V. REGULATED OUTPUT
- L 6.3 V.A.C.
- K 6.3 V.A.C.
- J TEST POINT
- H TEST POINT
- F -310 V. INPUT
- E TEST POINT (85 VOLTS)
- D TEST POINT.
- C TEST POINT.
- B +420V. INPUT
- A



MODEL	3500	3899	3121	6527
NEXT ASSY				
FINISH				
DRAWN	R. WARD	12-15-59	5-27-60	5-7-60
DATE				
UNLESS SPECIFIED, DIMENSIONS: INCHES				
TOLERANCES				
DECIMAL				
ANGULAR				
CHECKED				
PROJ. ENG.				
APPROVED				
MODEY				
SCALE				
SURFACE FINISH				
ITEM	2-3902	SEE PARTS LIST 3923		
MATERIAL				
QUANTITY				
TITLE	SCHEMATIC - VOLTAGE REGULATOR			
ISSUE	3921			
ISSUE	B			

NOTE: 1. UNLESS OTHERWISE SPECIFIED, ALL RESISTORS ARE 1/2W, 10%.
 2. RESISTORS R237, R238 LOCATED IN ASSOCIATED EQUIPMENT.

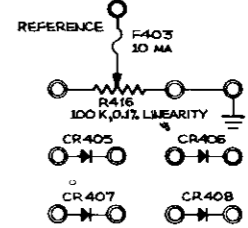
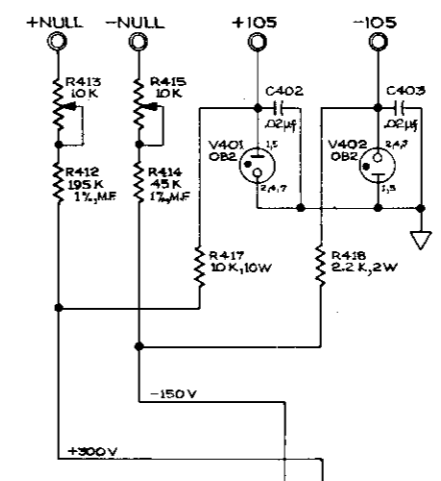
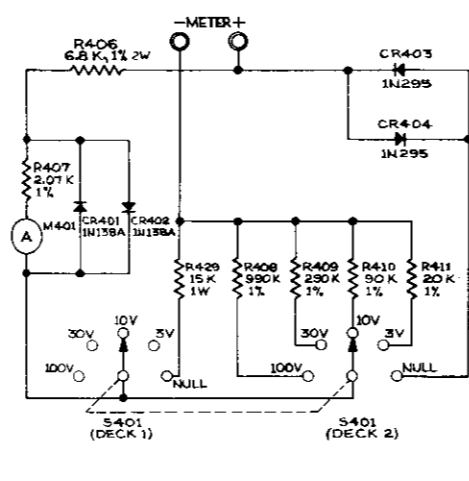
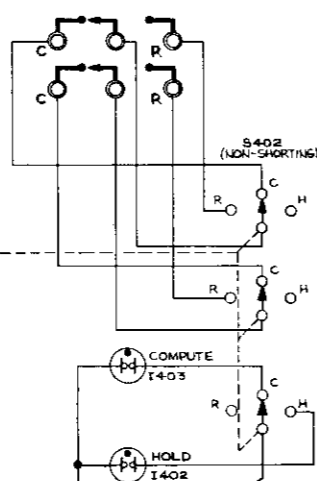
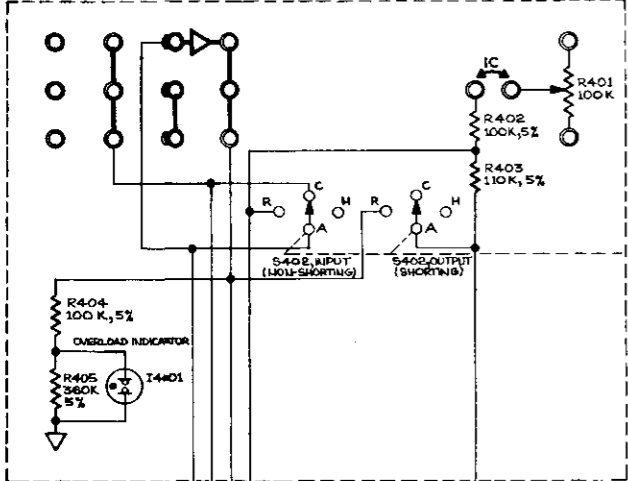
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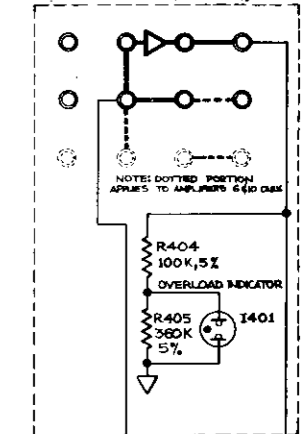
NOTE:
TOTAL RECTIFIED OUTPUT: 240 MA. MAX.

DRAWN BY: R. WARD	DATE 4-26-61	UNLESS SPECIFIED, DIMENSIONS: INCHES	DET. NO.	ITEM	MATERIAL	QUAN./UNIT
CHECKED BY: [Signature]	DATE: 5-1-61	TOLERANCES: DECIMAL ANGULAR SURFACE FINISH	COMP 700/RNFI	SEE PARTS LIST	3722	
PROJ. ENG: J. C. [Signature]	DATE: 5/5/61	SCALE	DOMINA SCIENTIFIC COMPANY			
APPROVED BY: [Signature]	DATE: 5/5/61	SCALE	TITLE			
MOBIL	NEXT/ASSEM.	SCALE	SCHEMATIC-POWER SUPPLY			
3500	3899	SCALE	DWG. NO. 3890			
3121	6527	SCALE	ISSUE A			
(ASSEMBLY 2-3501)						

AMPLIFIER #1 (TYPICAL INTEGRATOR CIRCUITRY-AMPLIFIERS 1 THRU 5)



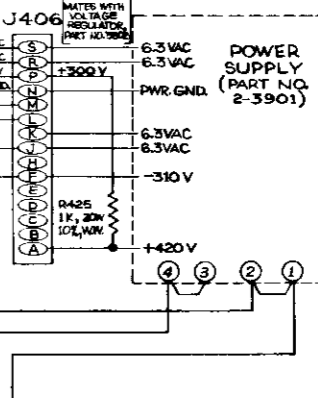
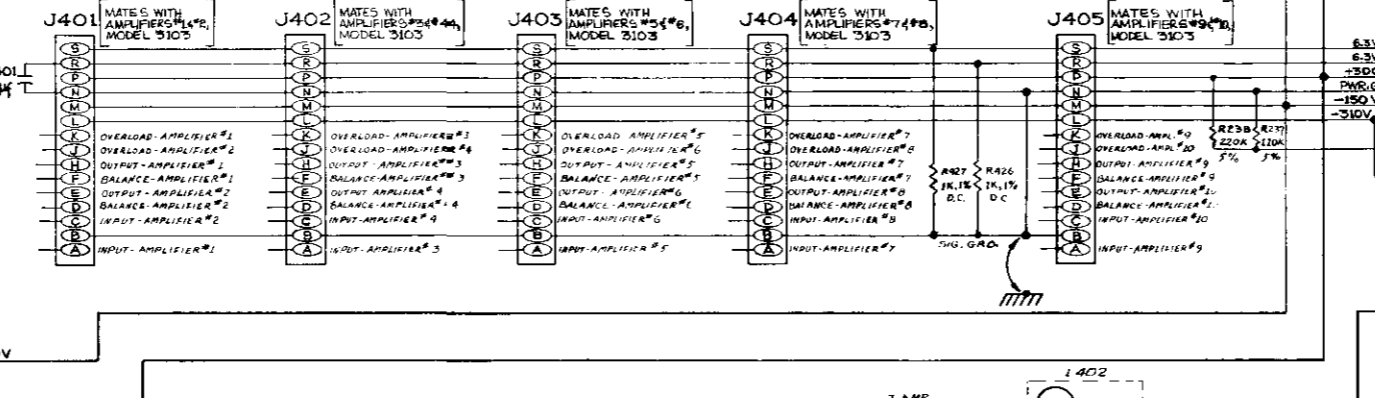
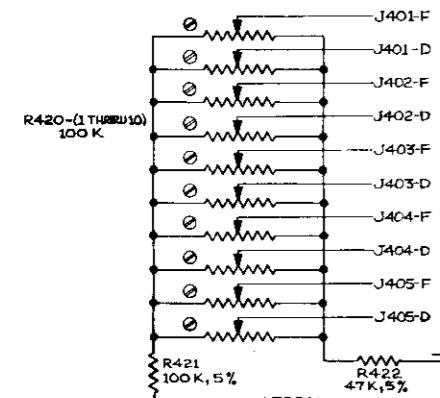
AMPLIFIER #10 (TYPICAL SUMMER CIRCUITRY-AMPLIFIERS 6 THRU 10)



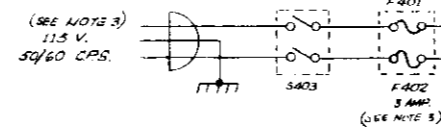
- J407 FRONT PANEL CONNECTOR
- 1 J401-A
 - 2 J401-C
 - 3 J402-A
 - 4 J403-C
 - 5 J404-A
 - 6 S402, INPUT 'C', AMP #2
 - 7 S402, INPUT 'C', AMP #3
 - 8 S402, INPUT 'R', AMP #2
 - 9 S402, INPUT 'R', AMP #3
 - 10 S402, OUTPUT 'X', AMP #2
 - 11 S402, OUTPUT 'X', AMP #3
 - 12 J401-H
 - 13 J401-E
 - 14 J402-H
 - 15 J403-E
 - 16 J404-H
 - 17 J402-P
 - 18 V401-1,5
 - 19 J402-N
 - 20 V402-2,4,6
 - 21 PROB. BD., TRUNK LINE #1

- J408 FRONT PANEL CONNECTOR
- 1 J402-C
 - 2 J403-A
 - 3 J404-C
 - 4 J405-A
 - 5 J405-C
 - 6 S402, INPUT 'C', AMP #4
 - 7 S402, INPUT 'C', AMP #5
 - 8 S402, INPUT 'R', AMP #4
 - 9 S402, INPUT 'R', AMP #5
 - 10 S402, OUTPUT 'A', AMP #4
 - 11 S402, OUTPUT 'A', AMP #5
 - 12 J402-E
 - 13 J403-H
 - 14 J404-E
 - 15 J405-H
 - 16 J405-E
 - 17 J402-P
 - 18 V401-1,5
 - 19 J402-N
 - 20 V402-2,4,6
 - 21 PROB. BD., TRUNK LINE #2

AMPLIFIER BALANCE ADJUST



- NOTES:
1. SYMBOL DESIGNATES JACK ON PROBLEM BOARD; SILK-SCREENED NOMENCLATURE (IN HEAVY LINE) ASSOCIATED WITH PROBLEM BOARD JACKS SHOWED FOR REFERENCE ONLY.
 2. SIGNAL GND. POWER GND. CHASSIS GND.
 3. FOR 230V OPERATION REMOVE JUMPER BETWEEN TERMINALS 1-2, 3-4 AT INPUT TO 2-3901 & ADD JUMPER 2-3. REPLACE F401, F402, 3AMP (OSC. F401) WITH 1.5 AMP (OSC. F401). ADD R412 (OSC. R-0152) IN SERIES WITH FAN.



DRAWN R.WARD	DATE 4-21-60	UNLESS SPECIFIED, DIMENSIONS IN INCHES
CHECKED JAC	DATE 5/1/60	TOLERANCES DECIMAL ANGULAR
TEST USE J. J. J.	DATE 1/1/60	SURFACE FINISH
APPROVED R. J. J.	DATE 5/1/60	SCALE
MODEL 3500	REV. NO. 3932	TITLE SCHEMATIC-ANALOG COMPUTER

DOUGLAS SCIENTIFIC COMPANY
REV. NO. 3899