**SPECIFICATIONS:**

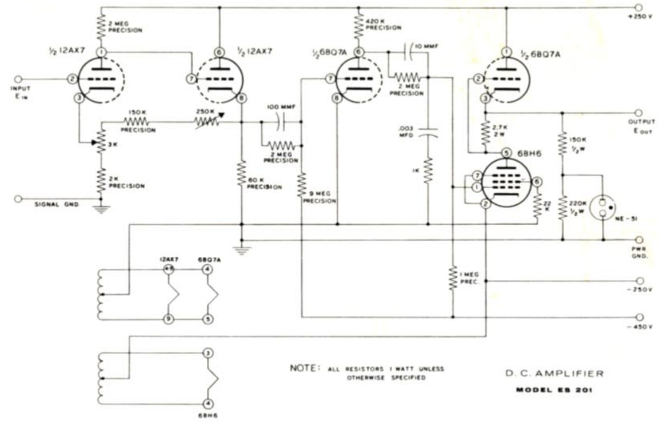
**This unit will contain the following:**

- 15 Amplifiers
- 30 Coefficient potentiometers
- 2 Auxiliary 10 turn potentiometers
- 6 flloating initial conditions
- 4 dual bias diodes
- 1 metering circuit with dividing network
- 2 operational relays
- 1 Amplifier power supply
- 1 Repetitive oscillator
- 1 Reference power supply

**Outstanding Features:**

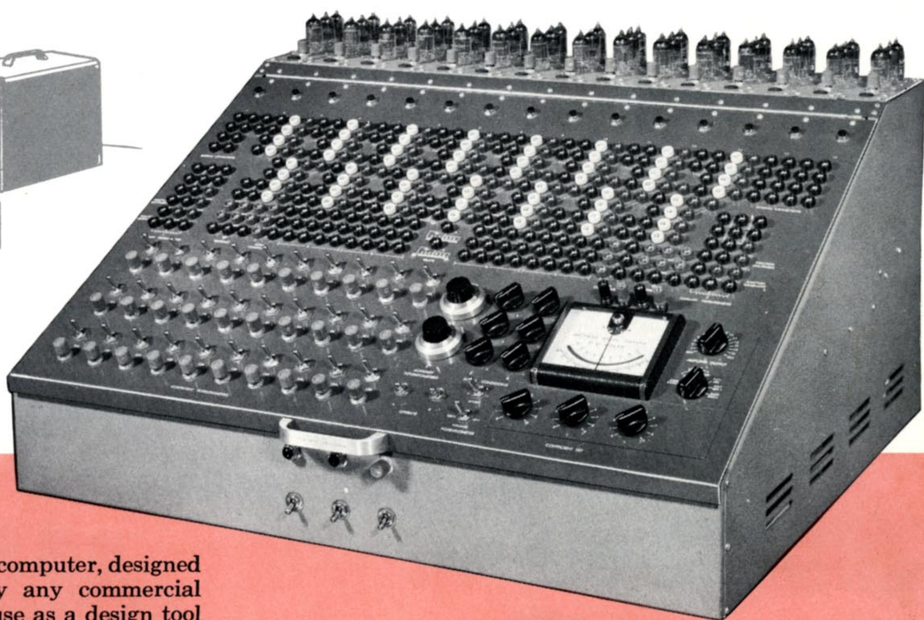
This unit is unique in its ability to calibrate for high accuracy. By means of a null meter the following functions may be accurately measured:

1—Coefficient setting
2—Overall gain from input to output of the amplifier
3—Initial Condition Set
4—Bias diode setting
5—Set up of a function generator
6—Throw voltages for operational relays




# HEATH INEXPENSIVE ELECTRONIC ANALOG

# computer KIT



## DESCRIPTION:

This is a highly flexible and accurate analog computer, designed to fill requirements not presently met by any commercial computer. It is an instrument suitable for use as a design tool in industry and universities. An advanced "slide rule" which permits engineering or research personnel to electronically simulate equations or physical problems and save many hours of calculation or experimentation. Ideal for solving practical problems in industry, and equally valuable for research, or instructional demonstration, in colleges and universities.

Because it is a kit, and the labor and overhead costs found in present day computers are eliminated, the Heath Computer can be obtained for use in situations where a computer was ruled out in the past because of cost. Definitely not a "gadget," but a high-quality, flexible, high-accuracy device designed to work for you. Incorporates such features as:

- *30 coefficient potentiometers, each capable of being set to an accuracy better than 1/10 of 1%.*
- *One standard reference supply for amplifier DC voltages.*
- *A nulling meter for accurate setting of computer voltages.*
- *A unique patch-board panel which enables the operator to "see" his computer block layout.*

## CABINET: ES-400

The computer cabinet houses power supplies, amplifiers, and computing components. It includes an accurate dividing network which introduces voltages to a null meter with an accuracy of better than 1/10 of 1%. By means of a switch, a potentiometer may be connected to the meter and read. This eliminates inaccuracy due to potentiometer nonlinearity, or loading.

The dividing network and meter may also be used to set up the initial conditions, to off-set bias diodes, and to read any voltage which appears at the amplifier. The meter may be switched to any of the 15 amplifiers so they may be set to give full scale deflection of plus or minus 2, 20 and 100 volts. The board also has the plus and minus 100-volt standard available, which is used in the dividing network.

## AMPLIFIER POWER SUPPLY MODEL ES-2

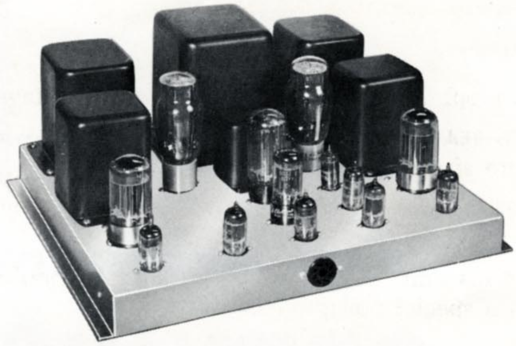
**PURPOSE:** To supply power to the amplifiers and function generators.

**OUTSTANDING FEATURES:** The plus and minus voltages are referenced from one standard and are so interconnected as to null or cancel power supply drift to the amplifiers.

**POWER OUTPUT:** Plus 250 V. at 250 mills, minus 250 V. at 250 mills, minus 450 V. at 50 mills, 6.3 V.A.C. at 12 amps, and 6.3 V.A.C. at 2.5 amps.

**TUBE COMPLEMENT:** 1—5651, 3—12AX7, 3—6U8, 2—6080, 1—6BX7, 2—5R4GY, 1—5U4GB.

**MOUNTING:** This unit may be mounted in the computer cabinet or on a rack for special purpose computers.



This power supply is a highly stable unit which features voltage regulation by a single 5651 tube. It is well rated for its use.

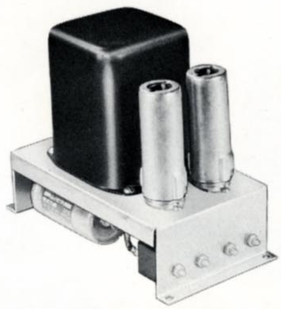
## INITIAL CONDITIONS MODEL ES-100

**PURPOSE:** To supply initial condition voltage to integrators.

**OUTSTANDING FEATURES:** Low drift rate, ungrounded, floating supply, highly shielded.

**TUBE COMPLEMENT:** 2—OB2.

**MOUNTING:** Three of these dual initial conditions power supplies mount inside the computer cabinet. This makes a total of six floating power supplies available.



This unit contains two separate supplies both of which can be varied from zero to 100 volts. Since they are floating supplies, they may be used for offsetting amplifiers and biasing diodes.

## AMPLIFIER MODEL ES-201

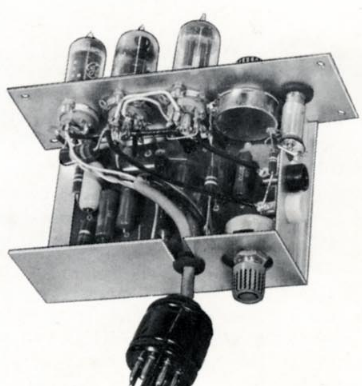
**PURPOSE:** To provide an amplifier for integration, sign changing, addition, and multiplication by a constant.

**OUTSTANDING FEATURES:** This unit is a highly stable unit with low drift. It is linear from plus 100 to minus 100 volts, will deliver 10 mills, and has an open loop gain of 50,000. Its phase shift when connected as a unity inverter is less than one degree at 1200 cycles.

**TUBE COMPLEMENT:** 1—12AX7, 1—6BQ7A, 1—6BH6.

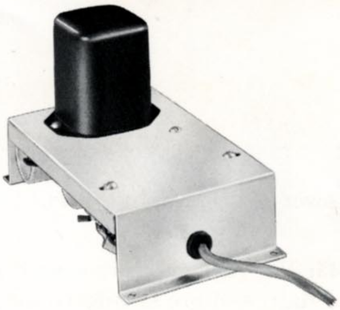
**POWER REQUIREMENTS:** Plus 250 V., minus 250 V., minus 450 V. Quiescent power is less than 5 watts.

**MOUNTING:** This unit may be mounted at the rear of the computer or on a standard rack mounting for special purpose computer.



This unit has a shielded chassis and makes use of printed circuits for ease of construction and uniformity. It is mounted at the top rear of the computer where it is shielded thermally and electrically from the rest of the computer.

## RELAY POWER SUPPLY — MODEL ES-151



**PURPOSE:** To supply power to operate the functional relays.

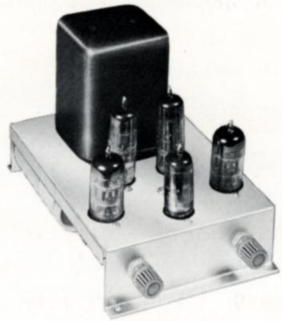
**OUTSTANDING FEATURES:** Has built in voltage surge network to insure simultaneous operation of the relays.

**POWER OUTPUT:** Designed to supply 50 volts across four 10,000 ohm relays.

**MOUNTING:** This unit may be mounted in the computer cabinet or in a special purpose computer.

This unit supplies a high surge voltage for rapid simultaneous operation of the relays, then the voltage drops to that necessary to hold the relays.

## REFERENCE POWER SUPPLY — MODEL ES-50



**PURPOSE:** To supply highly stable and accurate reference voltages.

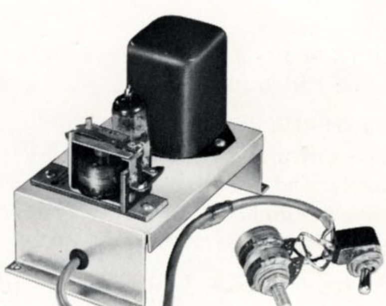
**OUTPUT:** Plus 100 volts and minus 100 volts.

**TUBE COMPLEMENT:** 2—6X4, 2—6U8, 1—5651.

**MOUNTING:** This unit may be mounted in the computer cabinet or in a special purpose computer.

In this supply the positive and negative voltages are slaved together and referenced from a single 5651. When operated with the constant voltage transformer, the output ripple, jitter, and noise is negligible.

## REPETITIVE OSCILLATOR — MODEL ES-505



**PURPOSE:** To provide repetitive operation of the functional relays.

**OUTSTANDING FEATURES:** Has an adjustable repetition rate of 0.6 to 6.0 times per second.

**TUBE COMPLEMENT:** 1—6J6.

**MOUNTING:** This unit may be mounted in the front of the computer cabinet or in a special purpose computer.

The repetitive oscillator allows problem solutions to be displayed on an oscilloscope.

HEATH ELECTRONIC ANALOG **computer** KIT

# price list

## SMALL COMPUTER—GROUP A $495

**GROUP CONTAINS:**

| | | |
|---|---|---|
| One | ES 2 | Amplifier power supply kit |
| One | ES 100 | Initial condition power supply kit. |
| One | ES 151 | Relay power supply kit |
| Five | ES 201 | Operational amplifier kits |
| One | ES 400 | Cabinet kit |
| One | ES 405 | Patch cord kit |

## MEDIUM COMPUTER—GROUP B $775

**GROUP CONTAINS:**

| | | |
|---|---|---|
| One | ES 2 | Amplifier power supply kit |
| One | ES 50 | Reference power supply kit |
| Two | ES 100 | Initial condition power supply kits |
| One | ES 151 | Relay power supply kit |
| Ten | ES 201 | Operational amplifier kits |
| One | ES 400 | Cabinet kit |
| One | ES 401 | Voltage regulator transformer kit |
| Two | ES 405 | Patch cord kits |
| One | ES 447 | Coefficient potentiometer kit |
| One | ES 505 | Repetitive oscillator kit |

## FULL COMPUTER—GROUP C $945

**GROUP CONTAINS:**

| | | |
|---|---|---|
| One | ES 2 | Amplifier power supply kit |
| One | ES 50 | Reference power supply kit |
| Three | ES 100 | Initial condition power supply kits |
| One | ES 151 | Relay power supply kit |
| Fifteen | ES 201 | Operational amplifier kits |
| One | ES 400 | Cabinet kit |
| One | ES 401 | Voltage regulator transformer kit |
| Three | ES 405 | Patch cord kits |
| Two | ES 447 | Coefficient potentiometer kits |
| One | ES 450 | Auxiliary coefficient potentiometer kit |
| One | ES 505 | Repetitive oscillator kit |

## EDUCATIONAL COMPUTER KIT $1,550

**GROUP CONTAINS:**

| | | |
|---|---|---|
| One | ES 2 | Amplifier power supply kit |
| Three | ES 50 | Reference power supply kits |
| Three | ES 100 | Initial condition power supply kits |
| Three | ES 151 | Relay power supply kits |
| Fifteen | ES 201 | Operational amplifier kits |
| Three | ES 400 | Cabinet kits |
| One | ES 401 | Voltage regulator transformer kit |
| Three | ES 405 | Patch cord kits |
| Three | ES 450 | Coefficient potentiometer kits |
| Three | ES 505 | Repetitive oscillator kits |

## INDIVIDUAL COMPONENT PARTS LIST

| Model No. | Description | Price |
|---|---|---|
| ES 2 | Amplifier power supply kit | $132.95 |
| ES 50 | Reference power supply kit | 22.95 |
| ES 100 | Initial condition power supply kit | 19.95 |
| ES 151 | Relay power supply kit | 11.95 |
| ES 201 | Operational amplifier kit | 14.95 |
| ES 400 | Cabinet kit | 247.95 |
| ES 401 | Voltage regulator transformer kit | 96.95 |
| ES 405 | Patch cord kit (contains 12 patch cords) | 16.95 |
| ES 447 | Coefficient potentiometer kit | 26.95 |
| ES 450 | Auxiliary coefficient potentiometer kit | 36.95 |
| ES 505 | Repetitive oscillator kit | 16.95 |

# HEATH ELECTRONIC ANALOG COMPUTER CABINET AND FRONT PANEL

## MODEL ES-400

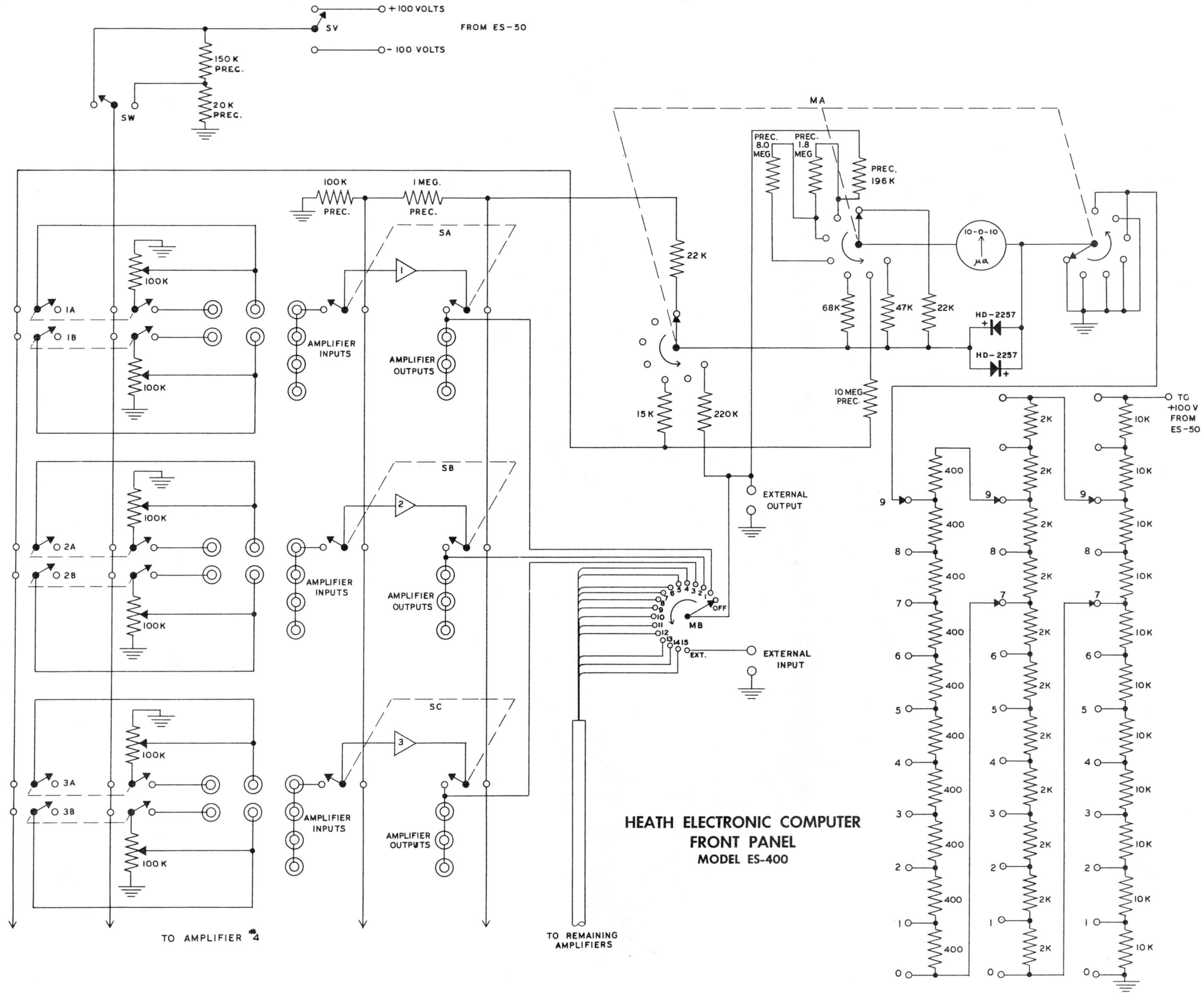
### SPECIFICATIONS

Power Requirements (complete computer): . . 105 - 125 volts AC, 60 cycles, 420 watts.

Dimensions: . . . . . . . . . . . . . . . . . . . . 26 1/2" long, 15" high, 32 1/2" wide.

Net Weight:
ES-400 . . . . . . . . . . . . . . . . . .
ES-447 . . . . . . . . . . . . . . . . . .
ES-450 . . . . . . . . . . . . . . . . . .

Total Shipping Weight: . . . . . . . . . . . . .



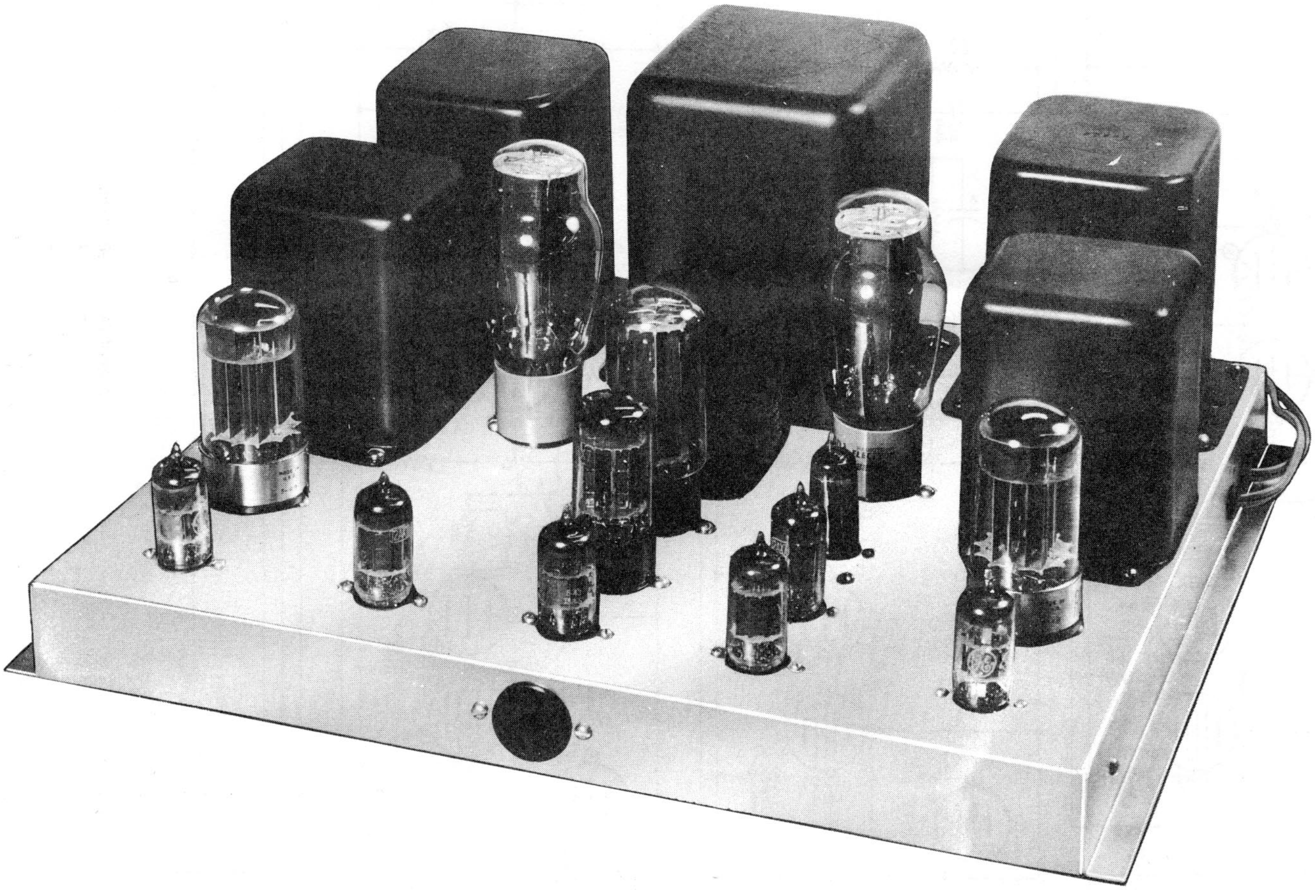

HEATH ELECTRONIC COMPUTER
FRONT PANEL
MODEL ES-400

# AMPLIFIER POWER SUPPLY

## MODEL ES-2

### TO BE USED WITH THE

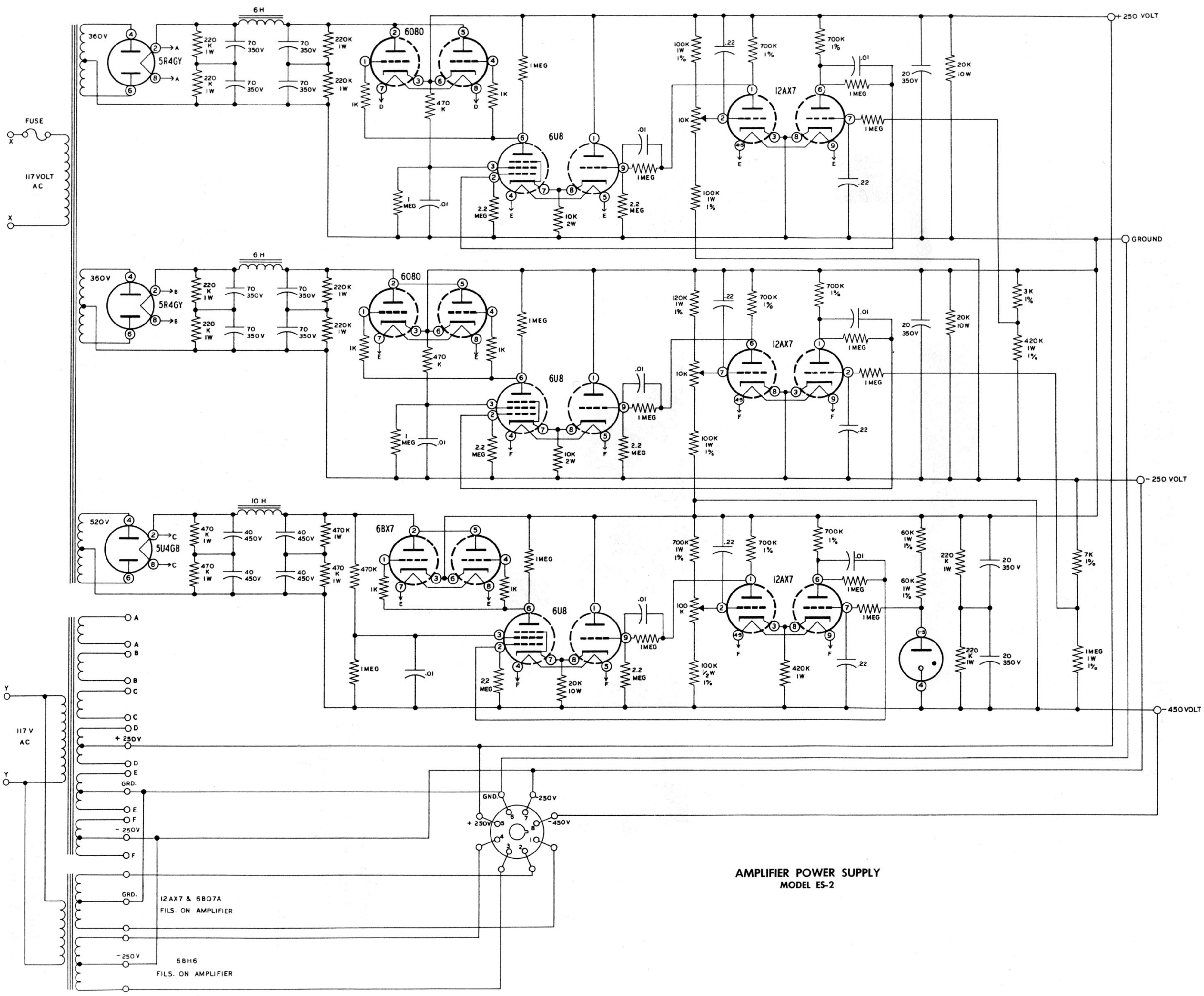
# HEATH ELECTRONIC ANALOG COMPUTER



SPECIFICATIONS

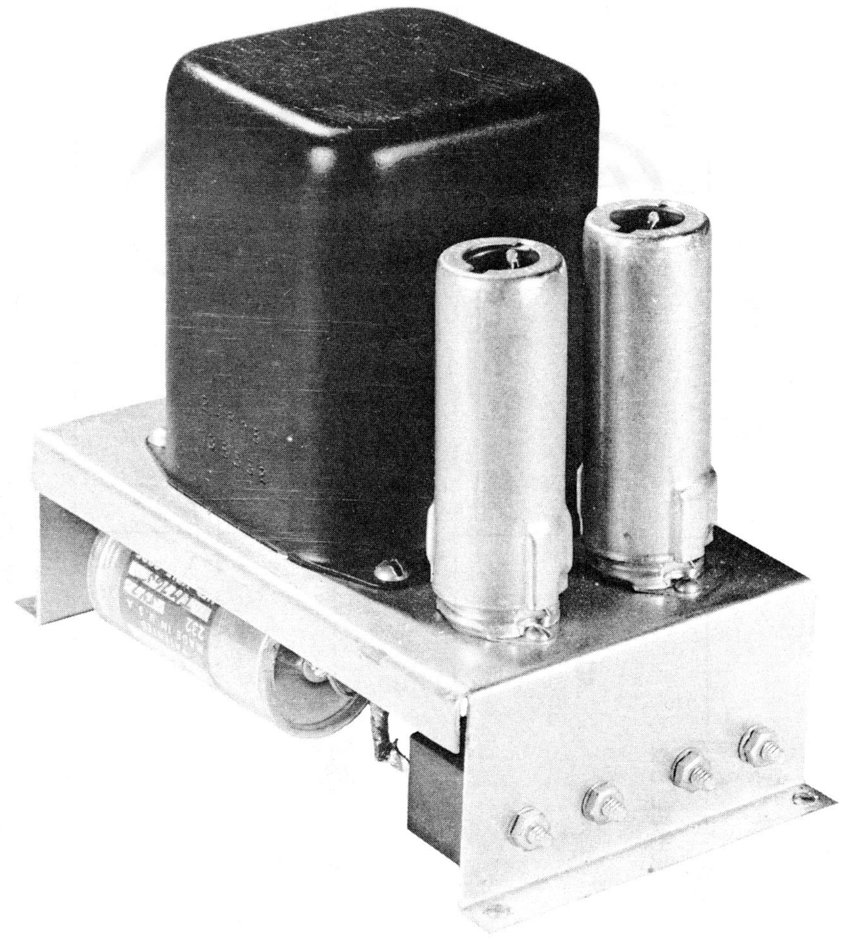
Power Requirements:

| | |
|---|---|
| Filament Input: . . . . . . . . . . . . . . . . . . | 117 volts AC, 60 cps, 105 watts. |
| High Voltage Input: . . . . . . . . . . . . . . . | 105-125 volts AC, 60 cps, 80 watts. |
| Outputs: . . . . . . . . . . . . . . . . . . . . . . . . | +250 volts DC at 250 ma.<br>-250 volts DC at 250 ma.<br>-450 volts DC at 50 ma.<br>Combined ripple jitter and noise for each output is less than 1 millivolt with regulated filament input.<br><br>Output voltages adjustable over 5% range.<br><br>6.3 volts AC at 12 amperes.<br>6.3 volts AC at 2.5 amperes. |
| Dimensions: . . . . . . . . . . . . . . . . . . . . . | 13" long, 16 1/4" wide, 6 7/8" high. |
| Net Weight: . . . . . . . . . . . . . . . . . . . . . | 42 1/2 lbs. |
| Shipping Weight: . . . . . . . . . . . . . . . . . | 48 lbs. |



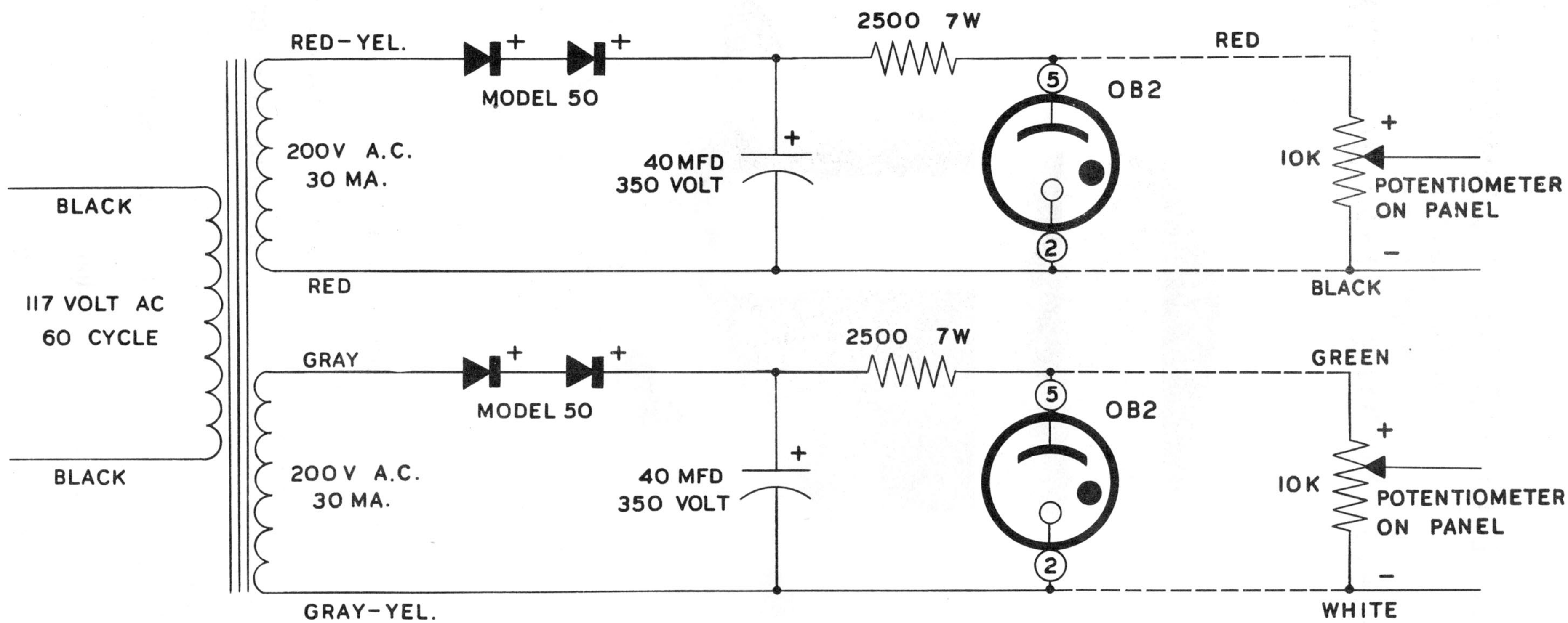

AMPLIFIER POWER SUPPLY
MODEL ES-2

# INITIAL CONDITION POWER SUPPLY
## MODEL ES-100
### FOR USE WITH
# HEATH ELECTRONIC ANALOG COMPUTER



SPECIFICATIONS

| | |
|---|---|
| Input: . . . . . . . . . . . . . . . . . . . . . . . | 117 volts, 60 cycles AC, 23 watts. |
| Output: . . . . . . . . . . . . . . . . . . . . . . | 0 to ±108 volts, 10 ma DC from each supply. |
| Tubes: . . . . . . . . . . . . . . . . . . . . . . | Two OB2. |
| Dimensions: . . . . . . . . . . . . . . . . . . . | 5 3/4" long, 4 5/8" high, 3 1/8" wide. |
| Net Weight: . . . . . . . . . . . . . . . . . . . | 3 lbs. |
| Shipping Weight: . . . . . . . . . . . . . . . . | 4 lbs. |



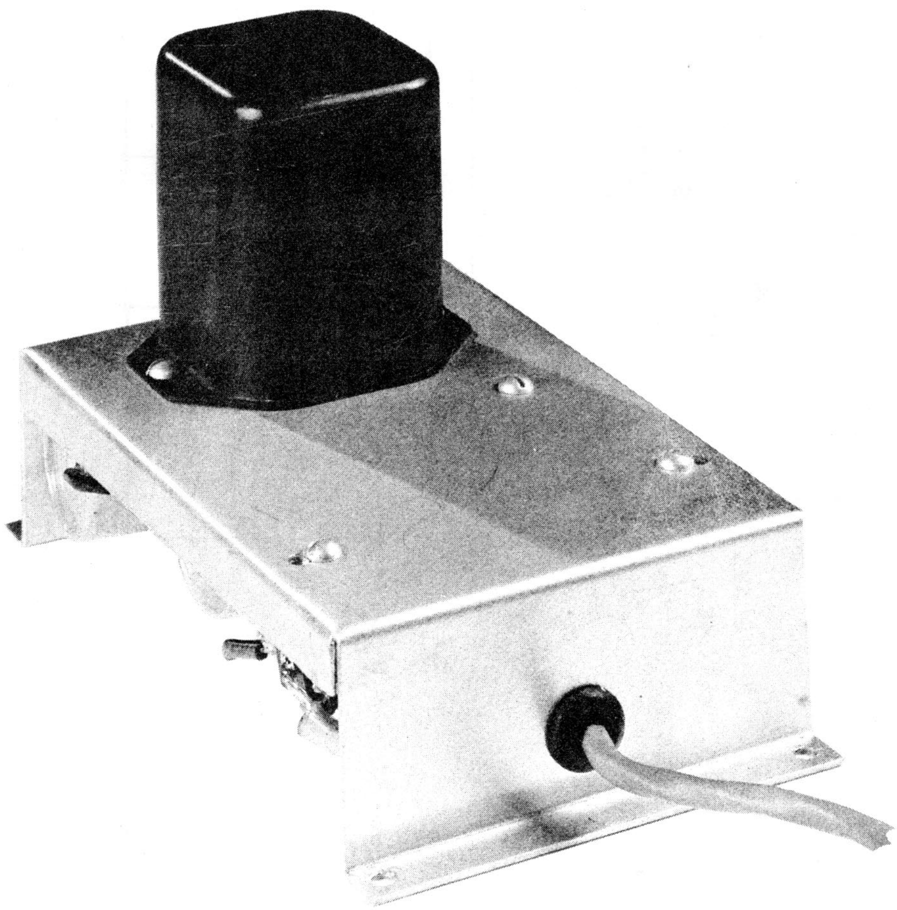

SCHEMATIC
INITIAL POWER SUPPLY
MODEL ES-100

# RELAY POWER SUPPLY

## MODEL ES-151

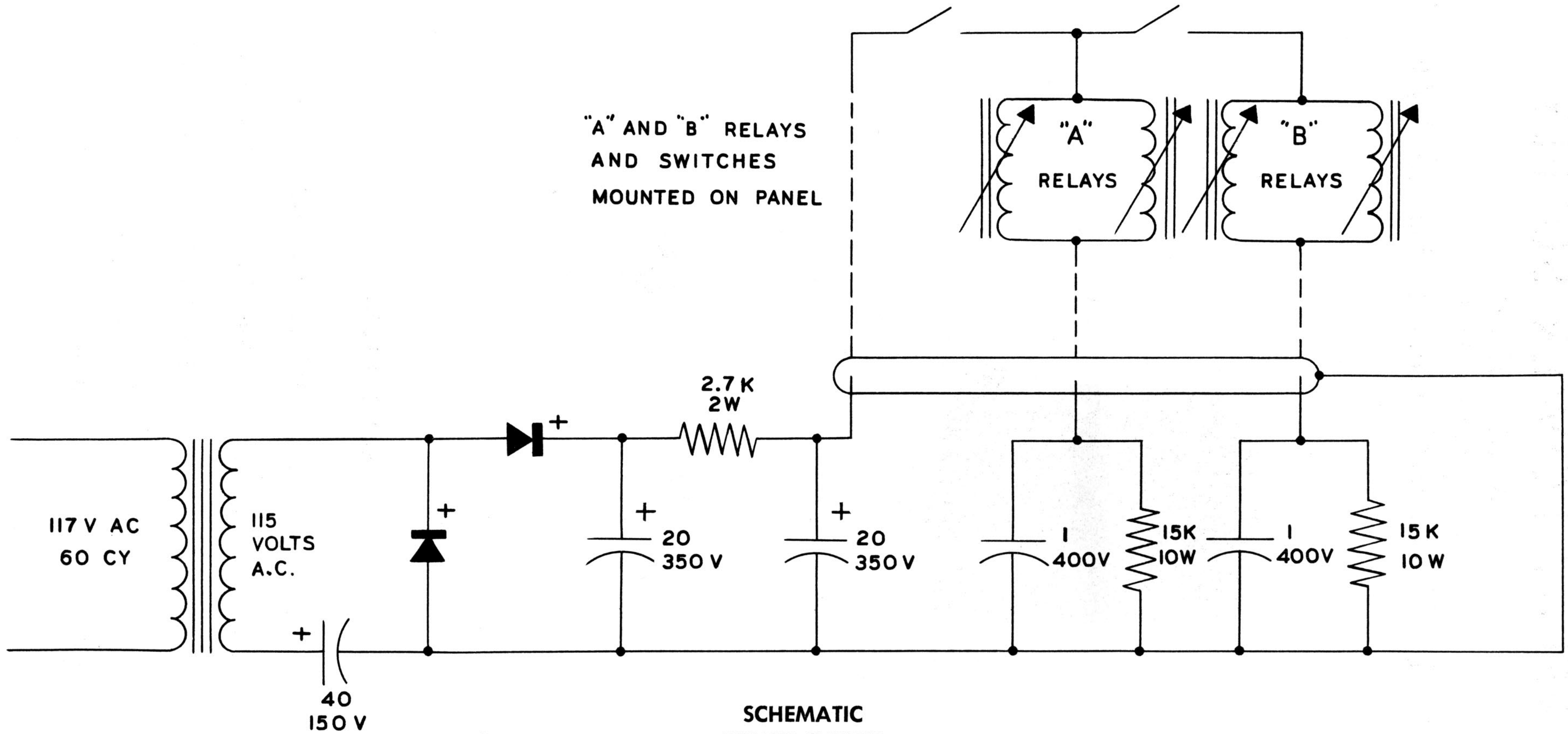
TO BE USED WITH THE

# HEATH ELECTRONIC ANALOG COMPUTER



### SPECIFICATIONS

| | |
|---|---|
| Power Requirements: . . . . . . . . . . . . . . . | 105-125 volts AC, 60 cps, 2 watts. |
| Output: . . . . . . . . . . . . . . . . . . . . . . . | 50 volts DC across 5 KΩ load. |
| Dimensions: . . . . . . . . . . . . . . . . . . . . | 5 3/4" long 3 5/8" wide, 3 3/4" high. |
| Net Weight: . . . . . . . . . . . . . . . . . . . . | 2 lbs. |
| Shipping Weight: . . . . . . . . . . . . . . . . . | 3 lbs. |




SCHEMATIC
POWER SUPPLY
MODEL ES-151

# REFERENCE POWER SUPPLY

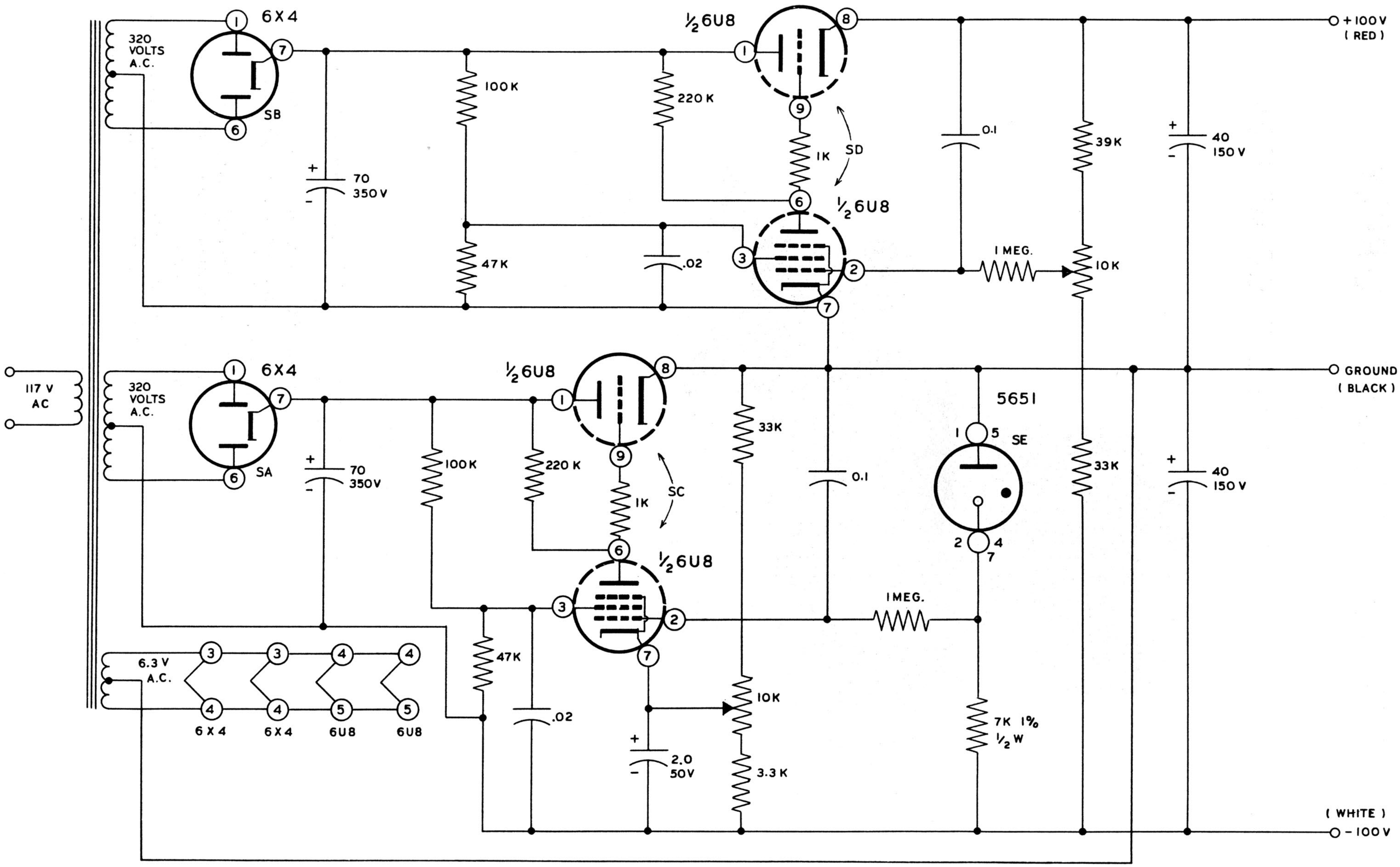
## MODEL ES-50

### TO BE USED WITH THE

# HEATH ELECTRONIC ANALOG COMPUTER

SPECIFICATIONS

| | |
|---|---|
| Input: | 117 volts AC, 60 cycles, 20 watts from constant voltage transformer. |
| Output: | 1. -100 volts DC, variable from -90 volts to -110 volts. Combined ripple, jitter and noise less than 2 millivolts.<br>2. +100 volts DC, variable from +90 volts to +110 volts. Combined ripple, jitter and noise less than 1 millivolt. |
| Reference: | A 5651 reference tube controls the negative supply. The positive supply is slaved to the negative supply. |
| Tubes: | Two 6X4; two 6U8; one 5651. |
| Dimensions: | 7 1/8" long, 4 3/4" high, 4 5/8" wide. |
| Net Weight: | 3 1/2 lbs. |
| Shipping Weight: | 5 lbs. |




# REFERENCE POWER SUPPLY

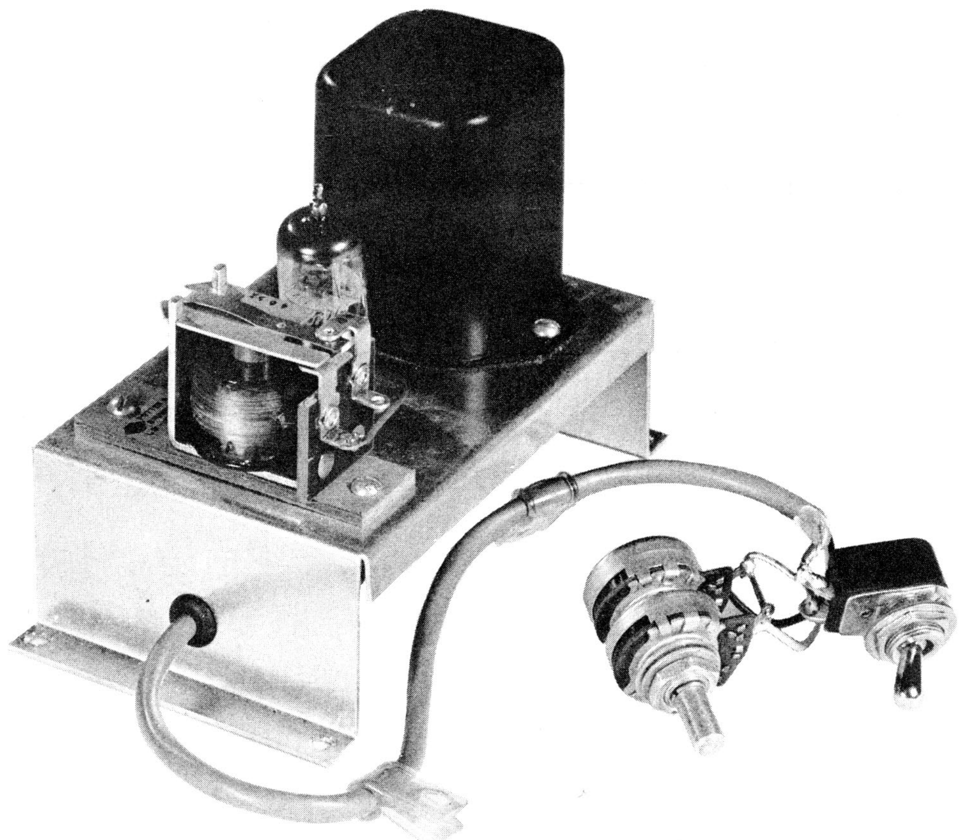
MODEL ES-50

# REPETITIVE OSCILLATOR

## MODEL ES-505

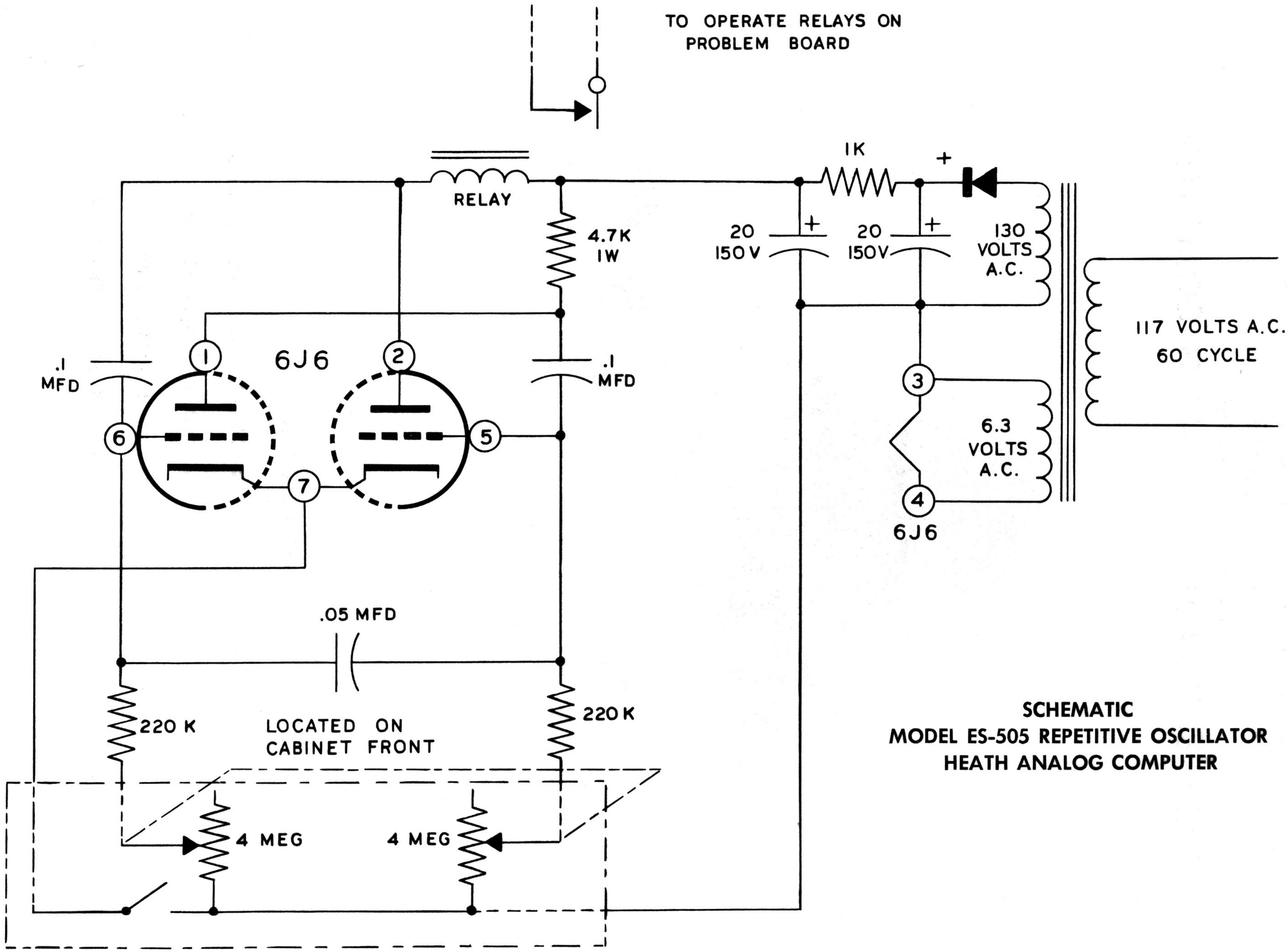
TO BE USED WITH THE

# HEATH ELECTRONIC ANALOG COMPUTER



### SPECIFICATIONS

| | |
|---|---|
| Input: . . . . . . . . . . . . . . . . . . . . . . . . | 105-125 volts AC, 60 cycles, 8 watts. |
| Frequency: . . . . . . . . . . . . . . . . . . . . . . | Adjustable from approximately 0.6 to 6 cps. |
| Tube: . . . . . . . . . . . . . . . . . . . . . . . . | 6J6 in multivibrator circuit. |
| Dimensions: . . . . . . . . . . . . . . . . . . . . . | 5 1/2" long, 3 3/4" high, 3 1/8" wide. |
| Net Weight: . . . . . . . . . . . . . . . . . . . . . | 2 lbs. |
| Shipping Weight: . . . . . . . . . . . . . . . . . . | 3 lbs. |



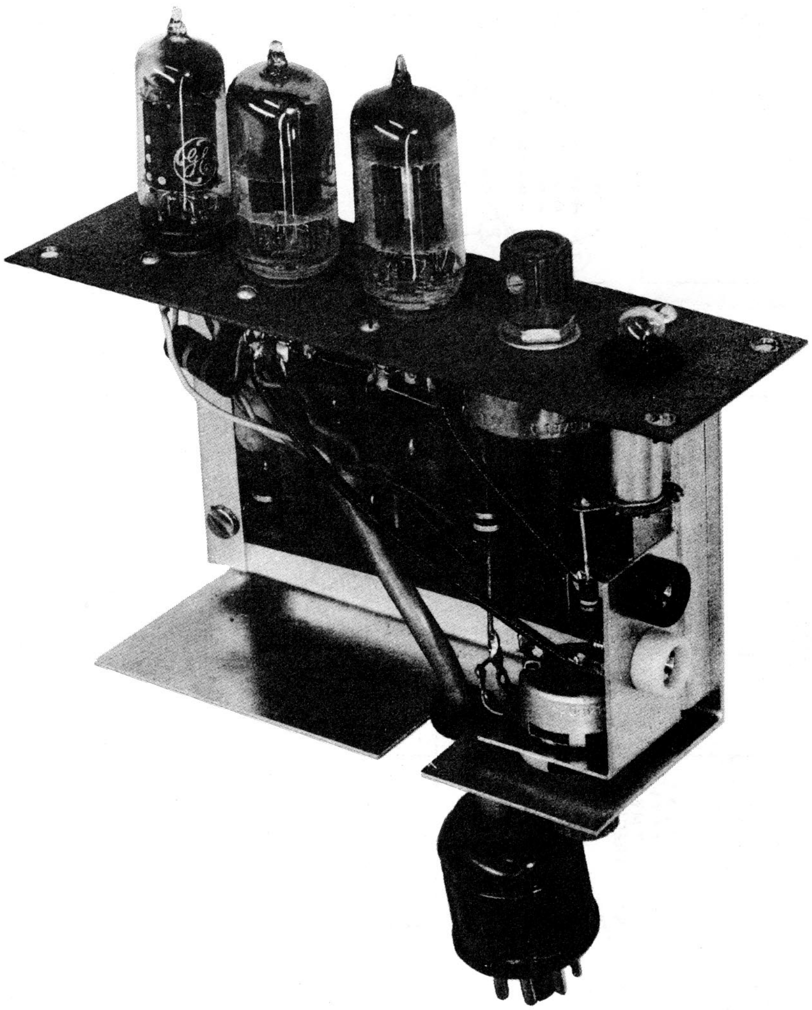

SCHEMATIC
MODEL ES-505 REPETITIVE OSCILLATOR
HEATH ANALOG COMPUTER

# DC AMPLIFIER

## MODEL ES-201

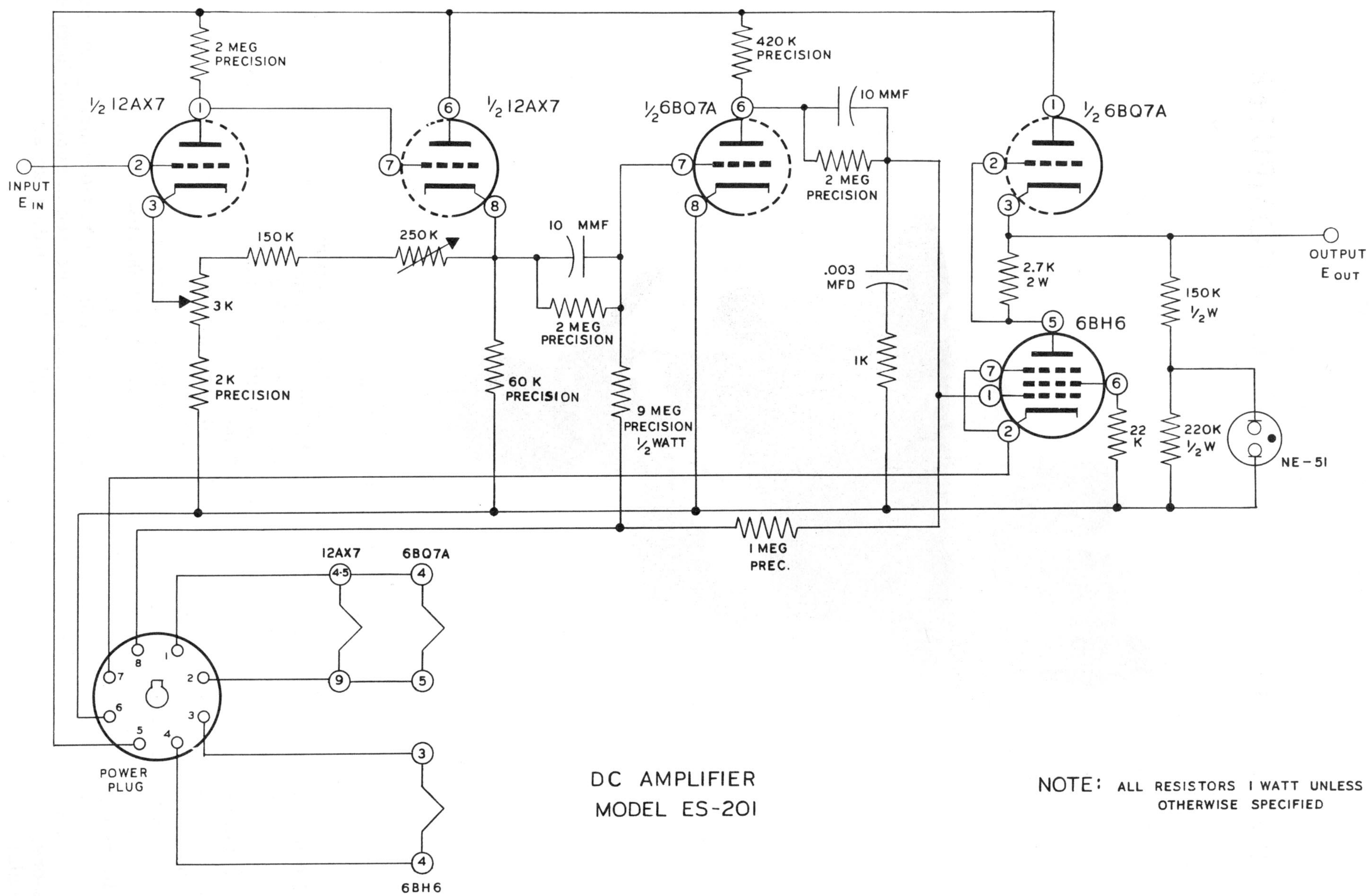
TO BE USED WITH THE

# HEATH ELECTRONIC ANALOG COMPUTER



## SPECIFICATIONS

| | |
|---|---|
| Tubes: | 12AX7, 6BQ7A, 6BH6. |
| Power Requirements: | +250 volts at 15 ma.<br>-250 volts at 15 ma.<br>-450 volts at 0.2 ma. |
| Quiescent Power: | 3 watts. |
| Output: | ±100 volts at 10 ma. |
| Open Loop Gain: | 50,000. |
| Frequency Response: | Flat to 2kc at unity gain. |
| Phase Shift: | Less than $1^{o}$ at 1200 cps. |
| Output Impedance: | Less than 50 ohms. |
| Drift: | 0.5 mv for 3 min referred to summing junction. |
| Noise: | Less than 2 mv referred to summing junction. |
| Dimensions: | 6" x 5 1/2" x 2" including tubes. |
| Net Weight: | 1 lb. |
| Shipping Weight: | 2 lb. |




DC AMPLIFIER
MODEL ES-201

NOTE: ALL RESISTORS 1 WATT UNLESS OTHERWISE SPECIFIED

# The Functional Considerations for a Low Cost Electronic Analog Computer

**By Chalmer E. Jones***


## ABSTRACT

THE GROWING APPLICATION of electronic analog computers has increased the demand for a variety of general purpose units. Each strikes a different median of accuracy, cost, convenience and flexibility. This paper deals with the design and functional characteristics necessary in a low cost, flexible unit capable of high accuracy when calibrated. Such a unit will find applications in industry and universities as a desk top electronic slide rule.


## INTRODUCTION

The first designs of a general purpose analog computer were those in which the manufacturer tried to guess the applications to which it would be used or could be used. He then designed an instrument flexible enough to solve most of the problems.

As time went by the better features were kept and poorer features were dropped. For example, such features as long busses were dropped while removable patch boards were added. At the present time it will be found that general purpose computers are really general purpose facilities made up of building block assemblies which are mounted together to meet the need of a particular application within a research laboratory, university or other installation.

These building blocks, such as amplifiers, multipliers and function generators, vary in design, quality and accuracy, but functionally maintain their identity until at the present time a large facility may be assembled with blocks from several manufacturers without impairing the performance of the computer.

## NEED

At the present time there is a trend to reduce cost and increase accuracy, maximizing convenience and flexibility. An increasing number of small computers is being sold in the overall market. The average weighted cost is approximately $60,000. Computers are still relatively expensive, running from $1,000 to $300,000 or $400,000 an installation.

It is becoming more apparent to industry and educational institutions that the computer is an advanced slide rule and is a necessary design tool. The engineer may conserve his design time by playing his hunches on a simulator which would have been impossible a few years ago. For example, he may assemble and disassemble a control system five or six times a day by analogy, thus saving valuable time and money.

As this development grows and the quantity of engineering increases, it becomes apparent that low cost analog computers with a high degree of acceptable accuracy must be designed to enable the individual engineer in industry to solve his problems. Industries would be able to furnish each project engineer with a computer. Such a unit would make it feasible for universities to have not just one computer, but several to teach their theory and application. Such computers should be highly flexible, capable of high calibrated accuracy and convenient to use.

This computer would find the following applications:

1—A desk top unit, complete in itself, to solve equations of more than usual difficulty.

2—To try out simple circuits, portions of loops or transfer functions before tying up the time of a large facility.

3—As an auxiliary to a large installation, whereby the unit will be slaved to the operation of the larger unit, offering additional amplifiers or a transfer function of the system. For instance, such a unit may be set up in a large computer installation to simulate the emergency cooling of a reactor pile.

4—As an educational and research tool for use in universities.

5—As an auxiliary patch board and smaller computer whereby amplifiers of an existing facility might be sectioned off into the smaller unit.

6—Testing physical units such as controllers, meters, etc.

It was felt that such a unit could be designed by analyzing and evaluating each function. By simple circuitry and new techniques a unit could be produced capable of high calibrated accuracy and maintain its flexibility and convenience. The author warns the reader that not all combinations are to be discussed in this paper. This paper will present most of the design considerations required and suggest one set of functional solutions.

From this the reader may develop a feel for functional and operational considerations necessary in a general purpose computer.

## DESIGN FACTORS

Basically, a computer may be classified by means of four criteria, those of cost, accuracy, convenience and flexibility.

*Cost* has a relationship to quality of components, complexity of design and size of facility.

*Accuracy* depends upon the quality of the components, quality of units such as power supplies, reference standard and passive R-C components. Accuracy may be increased by proper calibration before each run, but this makes the unit less convenient.

*Convenience* in general is inversely proportional to the time necessary to set up and reach a solution to a particular problem. A computer is considered more convenient with features such as pre-determined integrators, summers, push-button potentiometer setting and removable patch board.

*Flexibility* refers to the availability of these computing elements. A computer is more flexible if the passive resistors and capacitors are not associated with a certain amplifier and may be used as any computing impedance.

As was mentioned, these computers must be low in cost and highly flexible with as high an accuracy as possible. With these criteria the functional characteristics will be considered.

## FUNCTIONAL CONSIDERATIONS

### Meter Layout

Perhaps the key to the design of this computer could be found in the readout meter and its functions. This unit may be used as a means of accurate calibration of the various components. Basically, the unit would be used for the reading of the output of all amplifiers, initial conditions and other voltages which might appear in the circuitry. In this unit a nulling device was chosen to increase accuracies as the meter sensitivity could be increased to a point where .1% readings were easily made. A dividing network capable of dividing a 100 volt reference supply into a thousand steps was chosen. It is possible to operate this dividing network by means of push buttons or selector switches. Fig. 1 shows the layout of a system with selector switch dividing network. The

***Assistant to the President, Heath Company, Benton Harbor, Michigan**

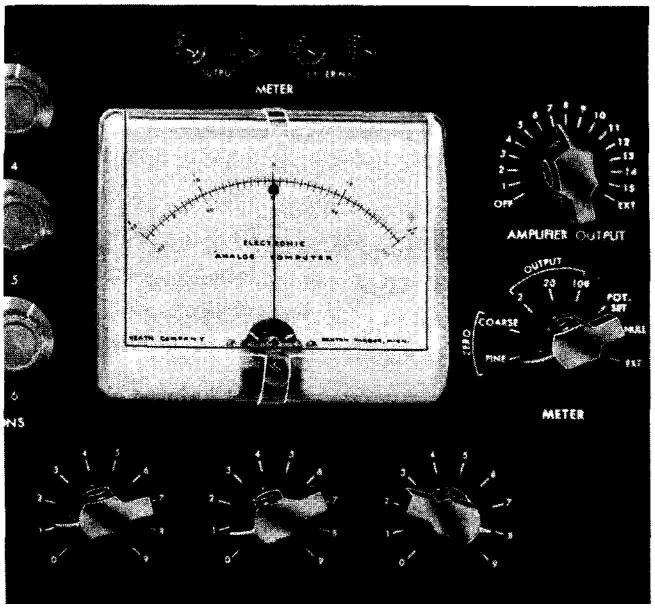



**Fig. 1 Meter Layout**

meter terminals are available for external readout on an oscilloscope or a chart recorder.

### Amplifier Layout

The amplifier as represented schematically on the patch bay must be highly flexible for a computer of this type. The layout must minimize the amount of patch cords used as well as provide

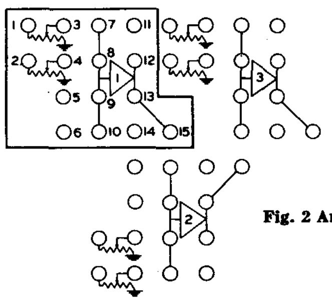


**Fig. 2 Amplifier Layout**

a logical computer diagram when fully "patched in". The passive R-C units may be plugged in externally or wired from behind the panel. Fig. 2 indicates the chosen layout of an amplifier. The feedback R-C components may be wired between Point 11 and 12 or 13 and 14. The impedance would then be introduced, making the amplifier a summer or an integrator by use of shorting bars returning to the grid. The progression of the computer diagram could be from Amplifier 1 to Amplifier 2 to Amplifier 3 (Fig 3-A). This could be accomplished by means of jumping plugs from Point 15 to the grid of the next amplifier (Fig. 2).

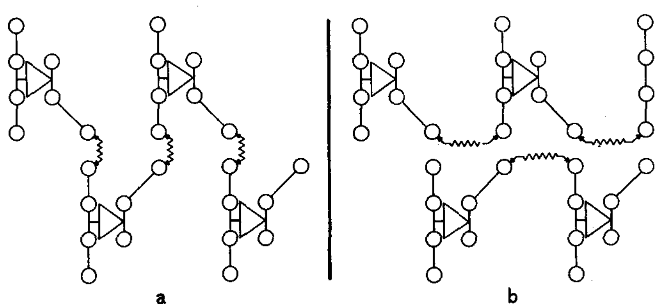


**Fig. 3 Computer Set-Up Diagram**

If the equation were of a simultaneous or cross-coupled type, a configuration of Figure 3-B might be used. It is, of course, recommended that high quality components such *as* polystyrene capacitors and precision resistors be used.

### Coefficient Potentiometers

These potentiometers multiply a voltage by a coefficient B less than one. The schematic is shown in Fig. 4-A. If a potentiometer with a dial is used, the linearity of the potentiometer must be high and the total resistance must be relatively low. The low resistance minimizes the loading error of the potentiometer. It can be seen that the arm has two paths to ground as is shown in Fig. 4-B. The grid voltage, Eg is near ground potential. Of course, the lower the total resistance of the potentiometer, the more power will be drawn. This requires a high output power of the amplifier. To overcome these problems and to increase the accuracy and convenience, the coefficient potentiometers are nulled to the standard dividing network (Fig. 4-C). Note that the loading error and any non-linear error disappears as the voltage is measured to the potentiometer arm while connected in the computer circuit. By switching the output of the amplifier to the null position of the readout meter (Fig. 4-D), the gain from input to output *may* be

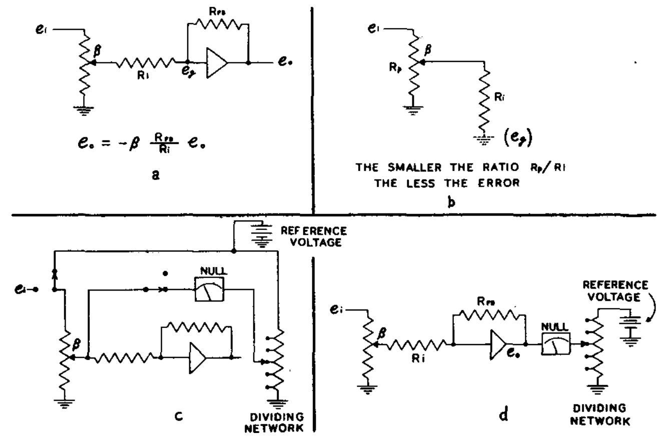



**Fig. 4 Potentiometer Connections**

set. This eliminates error due to mis-match of the input resistance and feedback resistance.

In Fig. 2 there were shown two coefficient potentiometers associated with each amplifier. This facilitates the functional connections just described.

### Initial Conditions

The initial conditions may be introduced by several means. The purpose, of course, would be to start a particular integrator with some voltage value when time is zero. Perhaps the most flexible way is by means of a floating power supply. The configuration in Fig. 5-A shows the connection of such a supply to the plates of a capacitor. This system allows for rapid re-sets and, therefore, repetitive solutions. With a floating power supply such *as* this the same units may be used to bias diodes (Fig. 5-B) or offset amplifiers (Fig. 5-C).

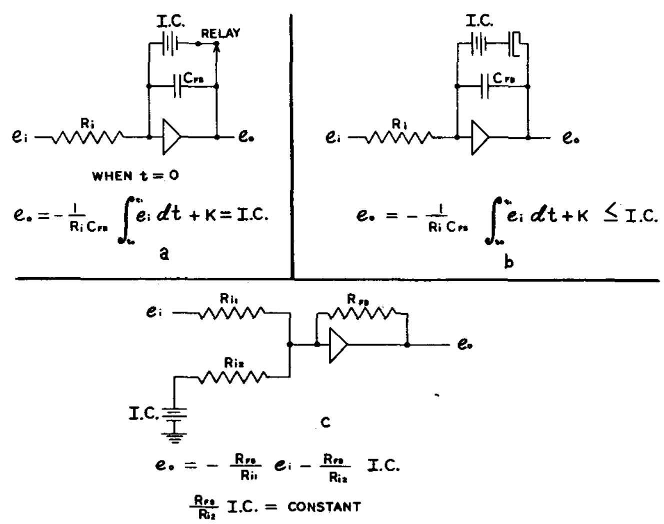



**Fig. 5 I.C. Connections**

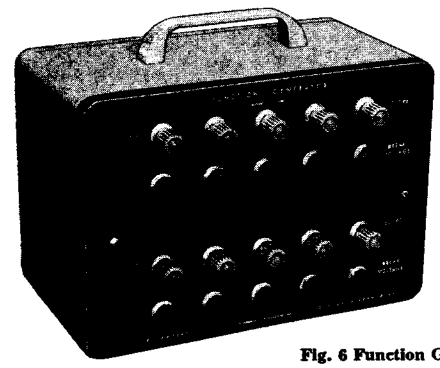


**Fig. 6 Function Generator**

Since the amplifiers were designed to swing between plus and minus 100 volts for ease in scaling problems and compatibility with other computers, the initial condition power supply should be variable between zero and 100 volts.

### Diodes

The purpose of diodes is to simulate non-linear functions such as back lash, dead zone, limits, stops, etc. Since most of these are dual value, two diodes are used and shown on the patch bay as dual units.

### Relays

The computer is reset and operated by means of entering initial conditions to the integrator. Relays must be operated for each capacitor. A second use of relays is to hold a problem in the midst of solutions, to enter new information or for recording purposes. Therefore, two sets of relays should be supplied. To increase the flexibility, the relay coils are connected to a jack on the patch bay. One relay set may be operated by means of the output of an amplifier to serve as a functional relay.

### Function Generators

Several types of non-linear function generators are manufactured and any may be used. Perhaps the most flexible for a unit of this size would be a bias diode straight line single function generator (Fig. 6). The unit could be set up by means of the null readout meter and the dividing network.

### Other non-linear units

Other non-linear units, such as multipliers, servo multipliers, and special purpose units may be used in conjunction with this computer. These would be connected to the patch jacks by cabling to external connectors.

In general the computer should be capable of being slaved to or mastering other computers. This enables its expansion to more than 15 amplifiers, which was the quantity chosen in this case. To provide for this, all grids and outputs should be brought to an inter-connecting bay at the rear of the computer.

### Summary

The key to such a low cost, flexible unit was found in using a standard voltage reference supply and a dividing network. This one feature allows an accurate measurement of :

1—Coefficient setting
2—Overall gain from input to output of the amplifier
3—Initial condition set
4—Bias diode setting
5—Set up of a function generator
6—Throw voltages for operational relays.

Other techniques which were developed were the layout of the amplifiers to allow a minimum of plugging and wiring and an inclusion of thirty nulled coefficient potentiometers. The final layout appears in Fig. 7. This is but one suggested computer layout to meet new demands of industry.

By analyzing the functions, it is possible to design an electronic analog computer for any median of cost, accuracy, flexibility and convenience.

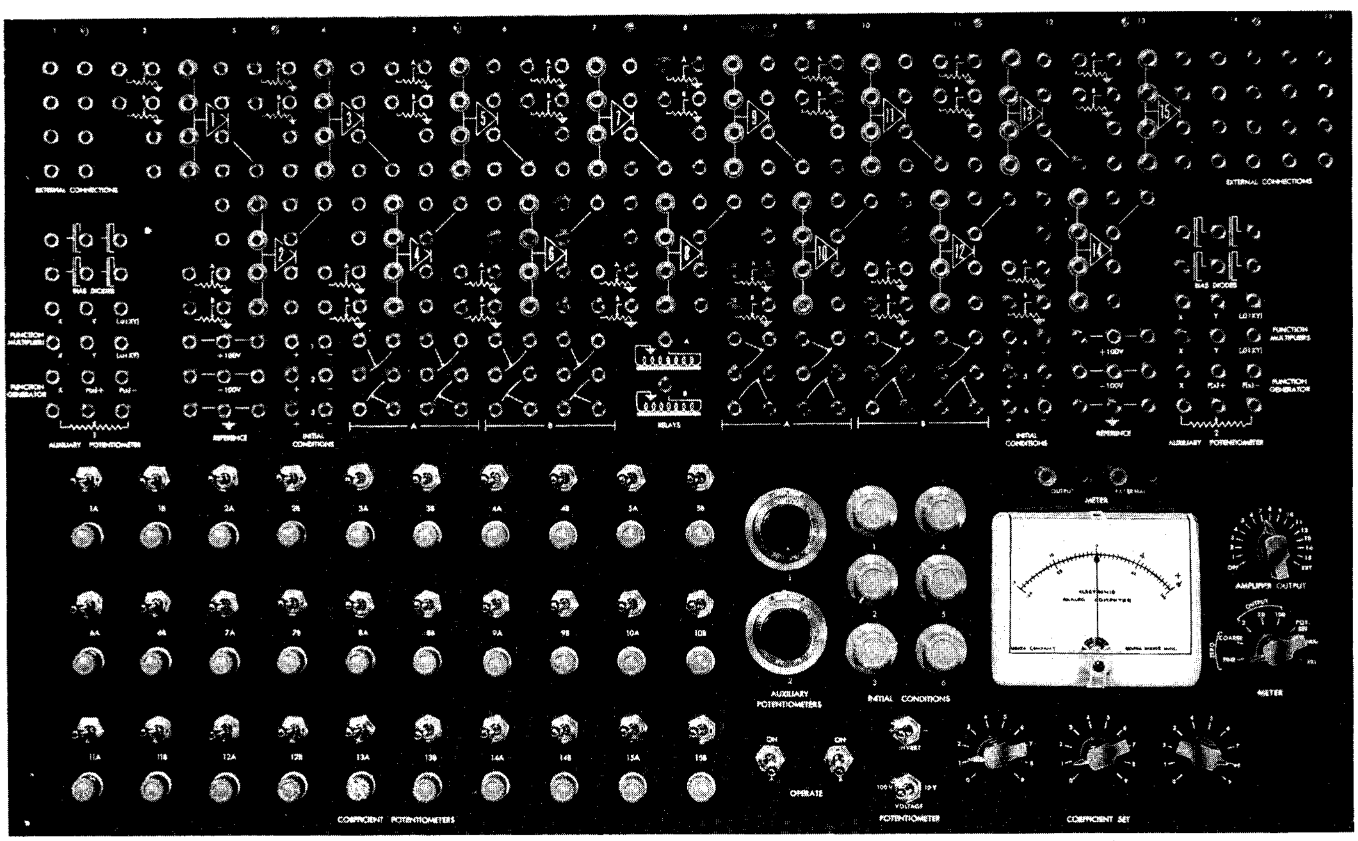


**Fig. 7 Final Layout**