

GENERAL ELECTRIC EDUCATIONAL PROJECTS

Project: Analog Computer

EF-140

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HOW TO USE THIS BOOK

To make it easier to build your analog computer and use it for solving mathematical problems, this book is divided into the following six parts:

- PART 1 - What You Will Do with This Kit
- PART 2 - How to Unpack Your Kit
- PART 3 - How to Assemble Your Computer
- PART 4 - How Your Computer Works
- PART 5 - Putting Your Computer to Work
- PART 6 - Suggestions for Further Reading

You should leaf through the entire manual before you assemble your computer to familiarize yourself with what you will be doing. But be especially sure to read Part 2, "How to Unpack Your Kit," before attempting to remove any of the components.

PART 1

WHAT YOU WILL DO WITH THIS KIT

Men have been using devices and machines of various kinds to help them with arithmetical calculations for thousands of years. The ancient Romans and ancient Chinese had the abacus, a wooden frame with rows of sliding beads. Experts can do many problems with astonishing speed on the abacus. Mechanical adding machines have been used in offices for decades.

Now, we have a new Age of Computers — electronic computers. In these, electrons do the counting and computing with the speed of lightning. Electronic computers were invented less than two decades ago. Already the tasks they perform are almost too numerous to count. Scientists use them for working out their theories and in the design, launching and tracking of satellites. Airplanes are tested without ever leaving the ground on simulated flights worked out on computers. Tomorrow's supersonic airliners will be completely dependent on computer-controlled automatic pilots; to prevent weak points that might blow out, supersonic transports probably won't have any windows. Giant computers are busy in business and industry, too. They run automatic refineries for oil companies, keep books for banks, help the Census Bureau count U.S. noses, keep inventory for giant manufacturing companies, help utilities keep track of customers' bills, assist the government in making sure everyone pays his proper taxes. There are even computers that can play chess and other games, and computers are being designed to obey instructions of the human voice and to translate languages.

In 1955, there were less than 100 giant

electronic computers at work in the United States, and most were used by mathematicians and physicists for complicated theoretical calculations. By 1960, there were more than 10,000 and their number was still on the way up.

There are two types of computers — digital and analog.

A digital computer counts, like a man counting on his fingers. It adds, subtracts, divides and multiplies by counting. However, the "fingers" it counts are pulses of electricity. It counts these so fast — a million or more pulses a second in some computers — that it can solve in minutes problems that would take a man days to work out.

Analog computers, on the other hand, work by comparing physical quantities. For instance, in the computer you will build and in all analog computers built today, numbers are multiplied by multiplying electric currents. Just how this works you will see later.

Analog computers are not nearly as accurate as digital machines. But there are some kinds of work, such as plotting the path of a satellite or missile, that they do more efficiently than a digital computer.

Like other simple analog computers, the one you are about to build gives approximate answers, accurate to two places. However, it was not designed to give exact answers to problems, but to introduce you to the *principles* of computers and to a new and fascinating field of science and technology — the design and use of computers. With the kit and manual, you will also learn how scientists and engineers work with numbers.

PART 2

HOW TO UNPACK YOUR KIT

Your Work Area

You will find assembly of the kit easier if you choose a flat surface, such as a table, in a good light as your work area.

What You Will Need

Everything you need to build your computer, including ready-to-use lengths of wire, is packaged in the kit except batteries. You

should buy four new D-sized batteries. These are standard flashlight batteries.

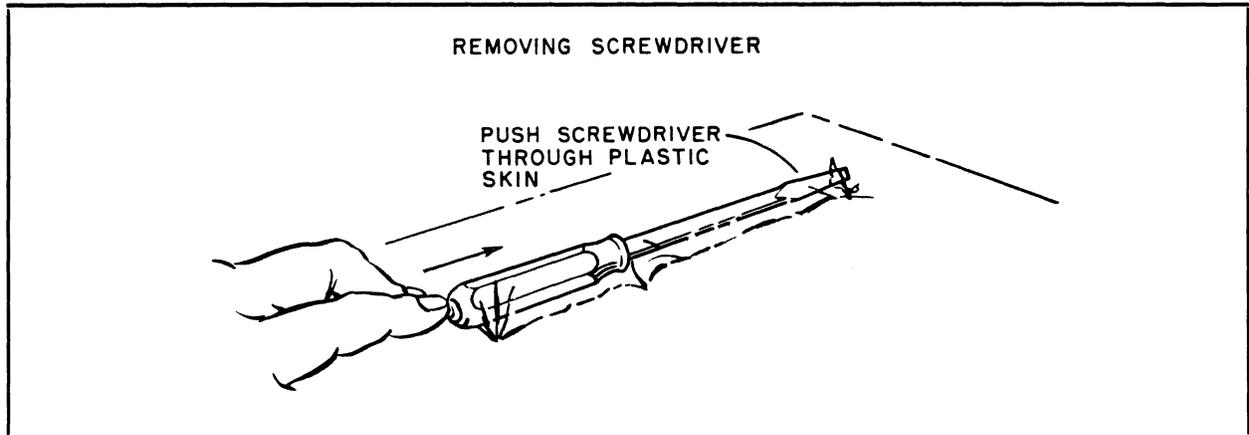
Opening the Kit

Hold onto both the clear plastic top and the black plastic bottom of the box. You will need them as part of the cabinet for your computer.

When you removed the top of the box, you found two transparent "skin packs" containing components for your kit. One of the packs

is screwed to the bottom of the box. Three mounting boards as well as three scale cards are also in the bottom of the box.

Work the screwdriver out of the larger skin pack as in *Fig. No. 1*. Remove the three long screws holding the smaller skin pack to the bottom of the box. Lay the two skin packs flat on your work table and identify the components by comparing them with *Fig. No. 2*.



FIGS. NO. 1 and 2

KNOW YOUR COMPONENTS

Here is some information about the principal components in the skin packs and in the bottom of your kit:

1. *Mounting Boards*. Three are supplied. The small one with the white upper surface and the rough underside is the circuit board on which you will mount the electronic components at the heart of your computer. The numbered and lettered holes are for the mounting of components and connectors. The large mounting board labelled "PROJECT: ANALOG COMPUTER" will hold the three computer dials and the scale plates. The third, with a rectangular hole in the center and the words "TONE" and "CALIBRATE" beneath round holes on either side, will support the on-off switch, tone control and calibration control.

2. *Scale Plates*. These three cards contain the scales you will use in solving problems with your computer. As you will see, changing scales to solve a particular problem is easy. On the reverse side of each scale is a Memory Board, containing formulas and other information on how to solve a great variety of problems.

3. *Potentiometers*. You have five potentiometers altogether. Potentiometers are also called "pots" or variable resistors. They contain thin wire or a piece of carbon that offers resistance to the flow of electric current. The amount of resistance can be varied by turning the shaft of the potentiometer. Three of your pots will be fitted with *scale knobs* and are for the computer dials. They will have a key part in carrying out multiplication and other mathematical operations electrically; exactly how they do this will be explained later. The other two pots will be used in the tone and calibration controls.

4. *Transistors*. The mighty midgets that have revolutionized electronics. Transistors are hardly bigger than aspirin tablets, but they can do nearly anything done by vacuum tubes and they do many things better. They are being used for pocket radios, hearing aids small enough to fit into eyeglass frames, giant computers, control systems for rockets and missiles, transmitters for space satellites. Three transistors will be used in your computer to generate a tone in an earphone. You will use this tone as a guide in finding the

correct answers to problems.

5. *Capacitors.* Electronic filters with the remarkable property of blocking direct current and passing alternating current. Capacitors help transistors operate efficiently.

6. *Resistors.* You have just read about potentiometers or variable resistors. Your kit also includes "fixed" resistors whose resistance cannot be changed. Fixed resistors help protect important components against currents that might damage them, and will also help your computer to operate efficiently.

7. *Earphone.* For hearing the tone that will help you find the correct answer on the answer dial.

8. *Tone Control.* To adjust the earphone tone to a pleasant pitch.

9. *Calibration Control.* To adjust the computer so that it can give correct answers.

10. *On-off Switch.* To turn your computer on and off.

11. *Hairpin-and-Spring Connectors.* For connecting wires without soldering or twisting them together.

REMOVING COMPONENTS

With the screwdriver, cut the plastic film around the components on the skin pack boards, as in *Fig. No. 3*. Peel the film to free components. Be careful not to cut any wires or damage components. Put them in small containers to protect them until you need them.

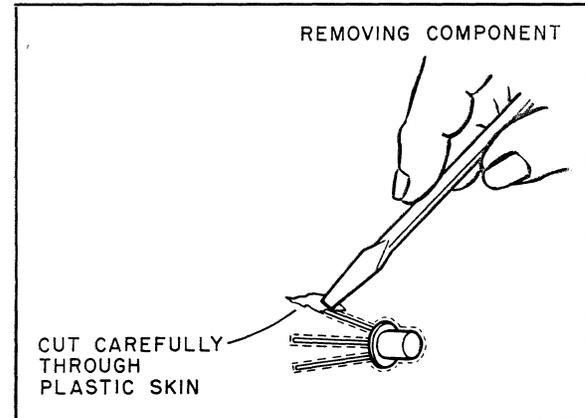
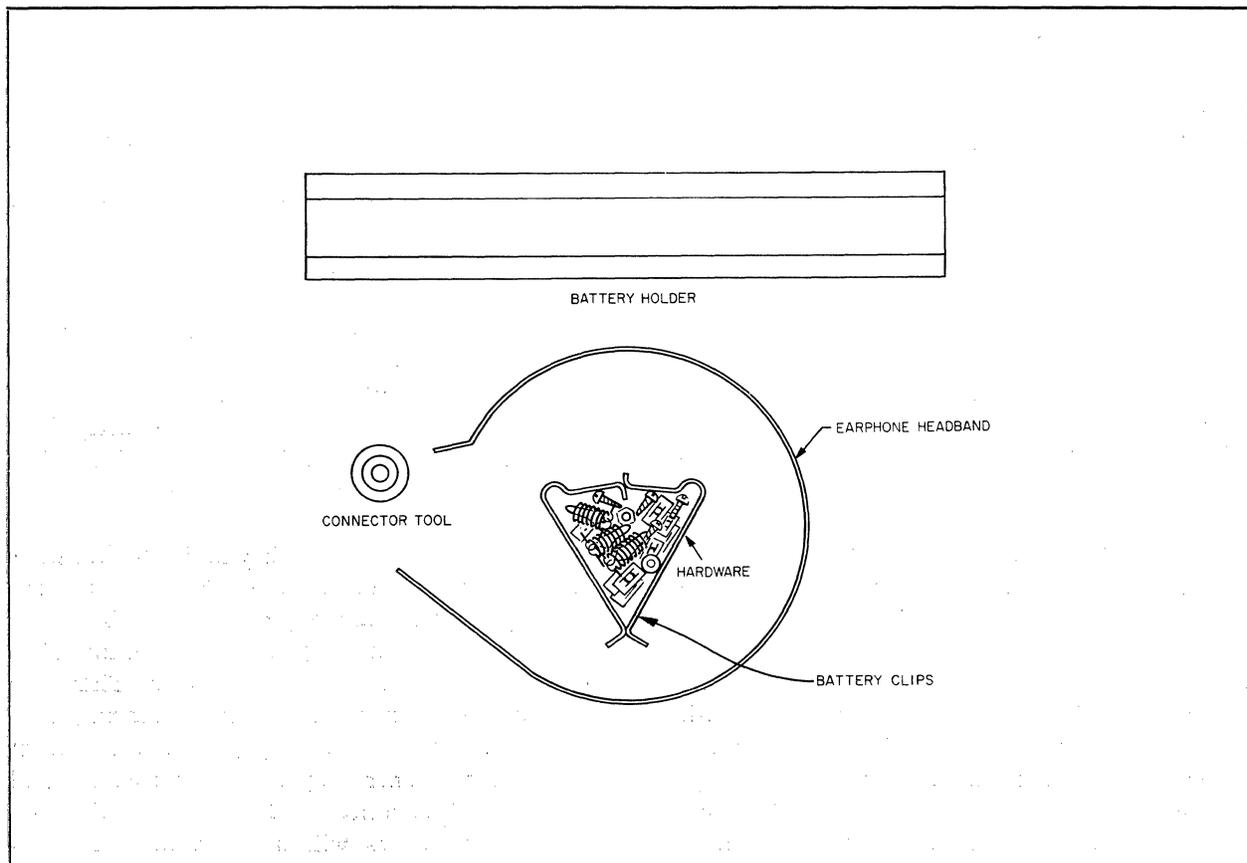
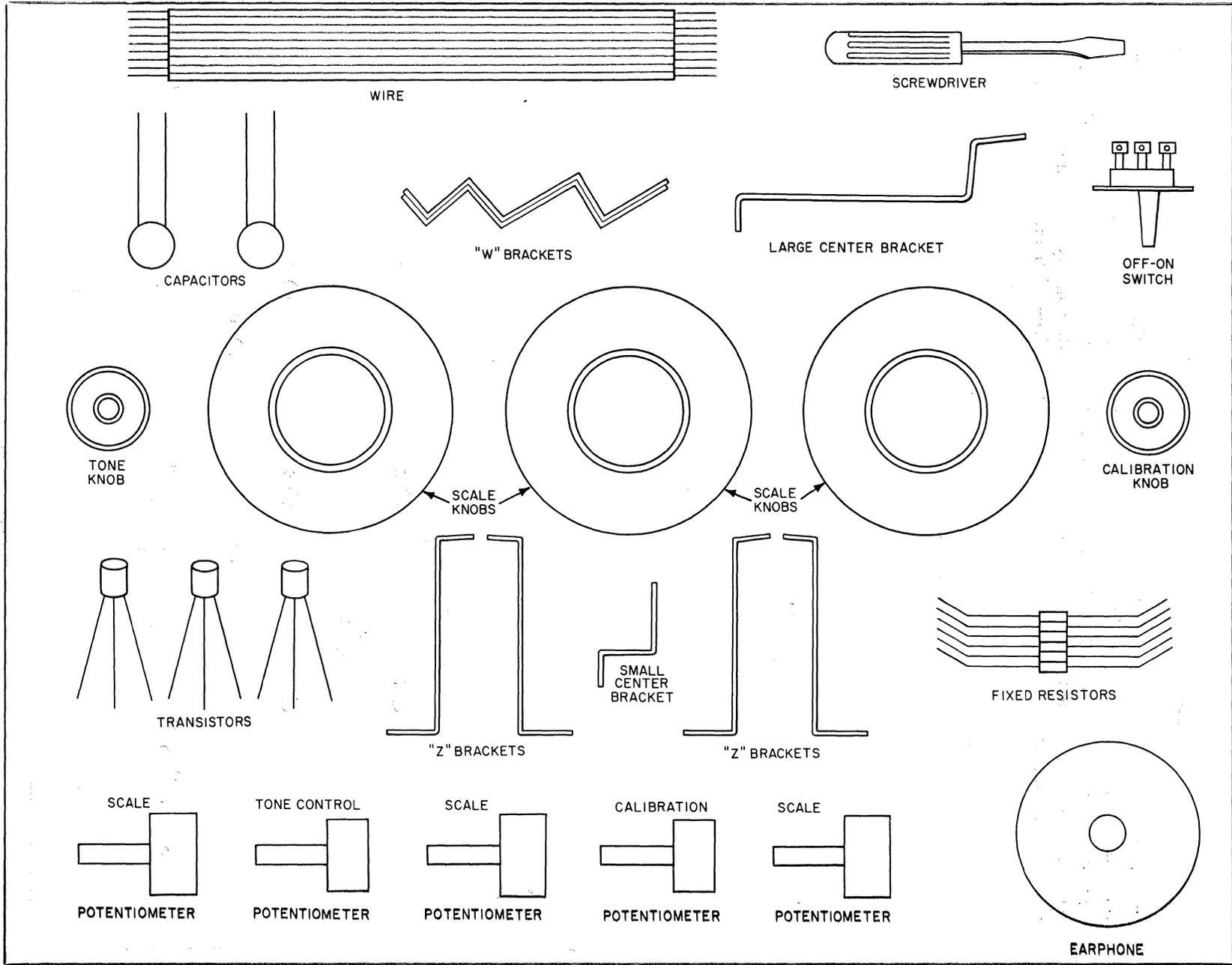


FIG. NO. 3



SMALL SKIN PACK

FIG. NO. 2



LARGE SKIN PACK
FIG. NO. 2

PART 3

HOW TO ASSEMBLE YOUR COMPUTER

Now that you are familiar with your tools and materials, take a look at the illustration on Page 2 to see the general arrangement your computer will have when finished. We're ready to build a computer.

Step 1.

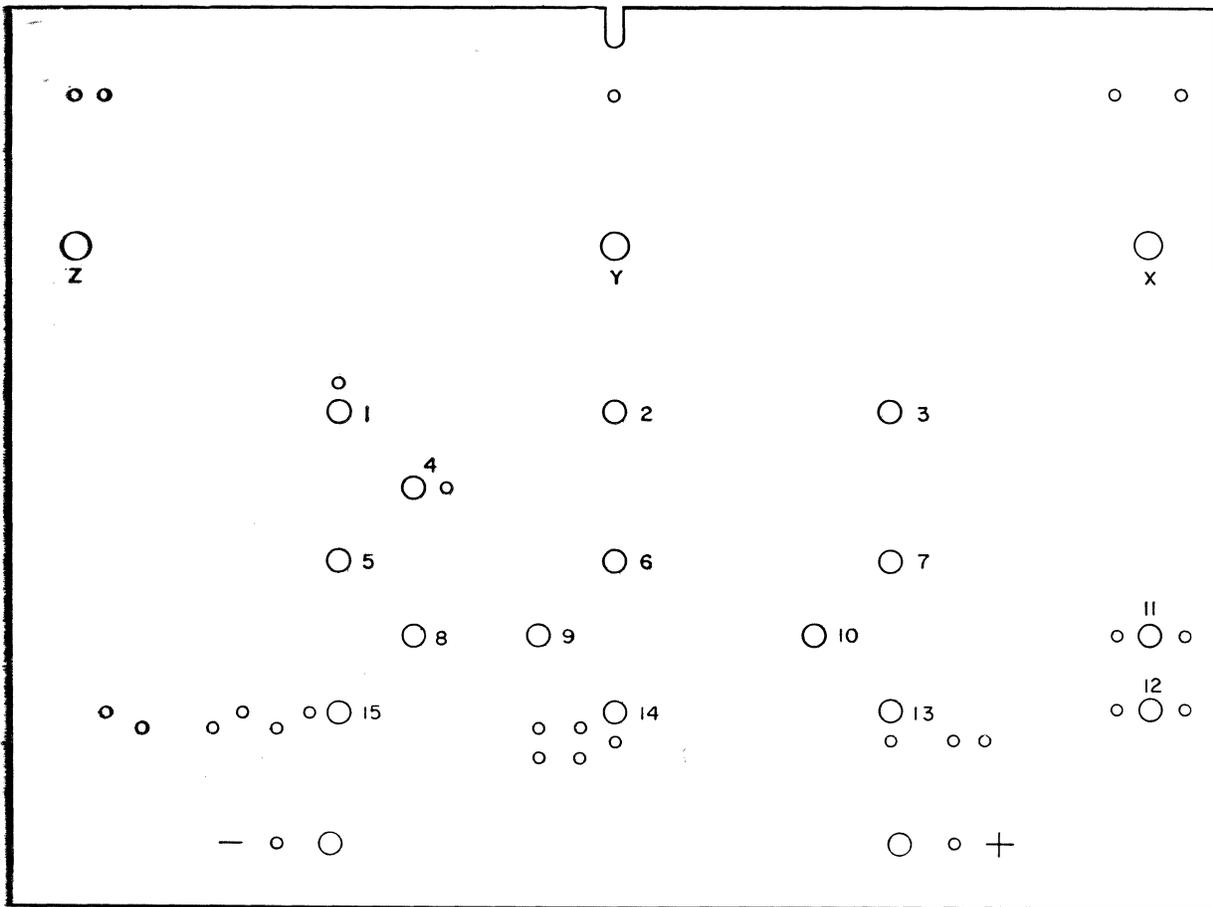
Place the circuit board in front of you with the white surface up and the U-shaped notch away from you, as in Fig. No. 4.

Install hairpin-and-spring connectors in holes number [1] through [15]. Here's one easy way to do it. Push the loop of the hairpins up through the bottom of the board, as in Fig. No. 5. Now place the board on a flat surface, such as a table top. Put a magazine under

the board so that the table won't be scratched. Using the connector tool as in the illustration, and with the small end of the spring down, ram the spring firmly over the pin until it clicks into place. You may have to wiggle it a bit to make it stay upright.

Step 2.

Mount battery clips and holder, being especially careful to match the positive and negative clips with the plus and minus signs on the board. You can identify each clip by its distinctive shape. The positive clip has a dotted pattern on one end. The negative clip is unmarked. (See Fig. No. 6.) Mount the clips and battery holder simultaneously. Clips fit



CIRCUIT BOARD

FIG. NO. 4

into the trough of the holder. A screw goes down through each clip, the battery holder, then the board. Put a flat speednut on to hold each screw. Be sure to put the nut on so that its corners can bite into the board. Tighten only enough to hold the battery holder and clips firmly. Batteries and connecting wires will be added later.

Step 3.

Inspect the five potentiometers furnished with your kit. Pick out the two marked 300 and the one marked 10K. Leave the two smaller pots, marked 200 and 200K respectively, aside for the moment. You will need them later.

The three pots with numbers are for three computer dials. The numbers refer to their resistance values: 300 means 300 ohms, and 10K means 10,000 ohms. (Resistance to the flow of electricity is measured in a unit called the *ohm*.)

Insert a 300-ohm pot through hole [X] from the upper surface of the board, as in *Fig. No. 7*. Point the three terminal prongs away from you. Secure the pot in this position with one of the five large nuts furnished in the kit. Tighten the nut so that the pot is held securely and will not turn when the dial knobs

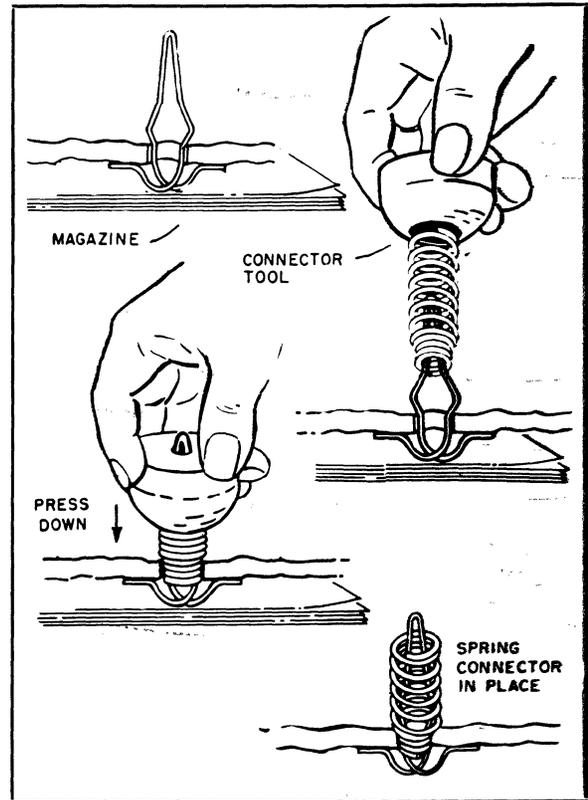


FIG. NO. 5

are attached. Use a pair of pliers **if necessary**.

In the same way, install the 10K pot in hole [Y] and the other 300-ohm pot in hole [Z].

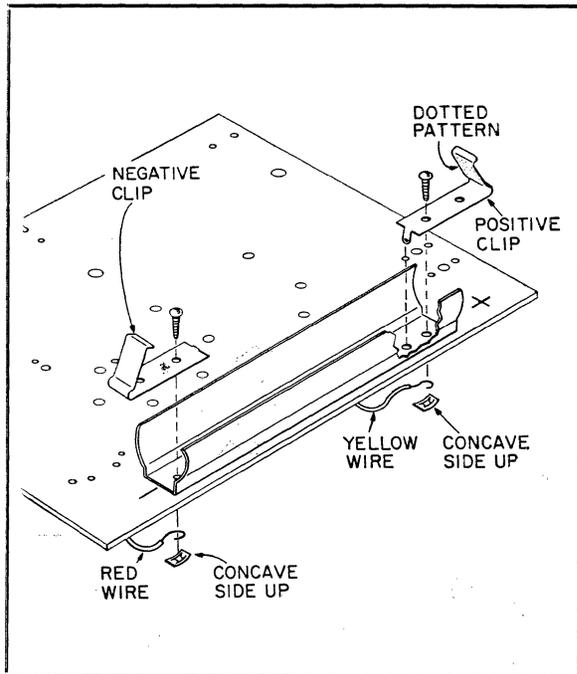


FIG. NO. 6

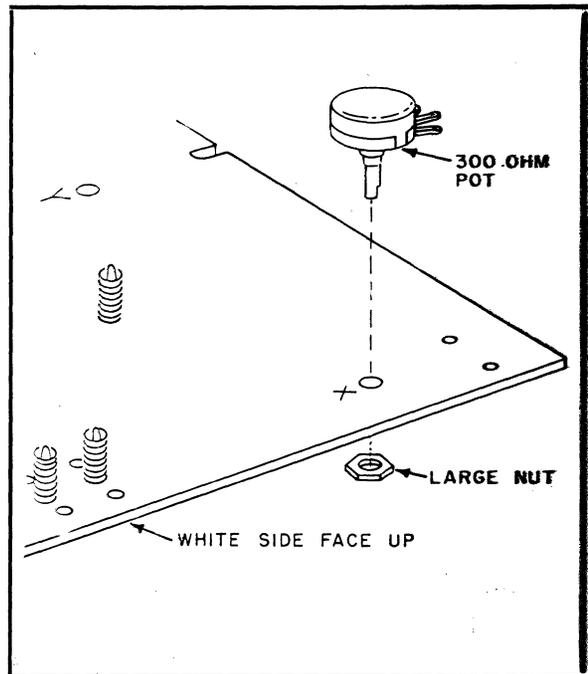
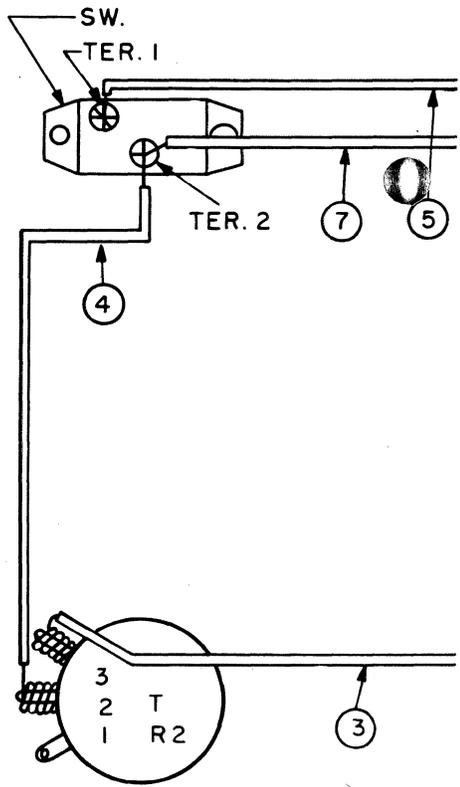
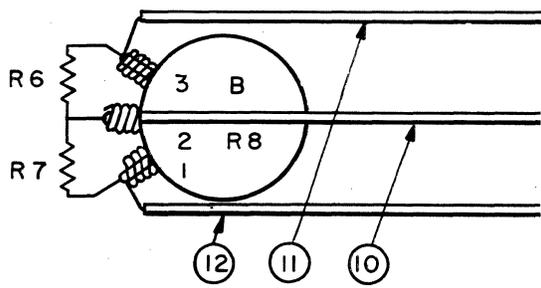
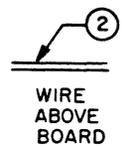
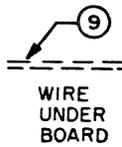
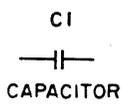
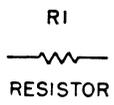
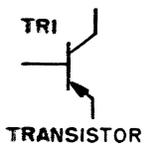


FIG. NO. 7

WIRE NO.	DESCRIPTION		FROM	VIA HOLES	TO
	LENGTH	COLOR			
1	7 3/4	BLACK	TER. 1 of Z	—	TER. 1 of Y
2	7 3/4	"	TER. 1 of Y	—	TER. 1 of X
3	11 3/4	"	CONN. 4	G-M-I	TER. 3 of T
4	6	RED	TER. 2 of T	—	TER. 2 of SW
5	7	"	BATTERY —	S-R	TER. 1 of SW
6	7 3/4	"	TER. 3 of Y	—	TER. 2 of X
7	9 1/2	"	CONN. 1	F-Q-P	TER. 2 of SW
8	10	BROWN	TER. 2 of Y	C-H	CONN. 11
9	14 1/2	"	TER. 2 of Z	A-J	CONN. 12
10	13 1/4	ORANGE	CONN. 13	N-U-W	TER. 2 of B
11	12 3/4	BLUE	TER. 3 of Z	B-Y-X	TER. 3 of B
12	17 1/2	"	TER. 3 of X	E-T-U	TER. 1 of B
13	5 1/2	YELLOW	BATTERY +	-O-	CONN. 14
14	9 3/4	"	TER. 1 of X	-D-	BATTERY +
15	2	BARE	CONN. 7	—	CONN. 3
16	2 1/2	"	CONN. 6	—	CONN. 10
17	3 1/4	"	CONN. 14	—	CONN. 15
18	6 1/4	"	CONN. 1	CONN. 2	CONN. 3



PART NO.	DESCRIPTION
R-1, R-5	1.5K 1/2 W. RESISTOR
R-2	200K POT.
R-3	10K 1/2 W. RESISTOR
R-4	22K 1/2 W. RESISTOR
R-6, R-7	33 1/2 W. RESISTOR
R-8	200 CARBON POT.
R-9, R-11	300 W.W. POT.
R-10	10K W.W. POT.
C-1, C-2	.05 M.F.D.
TR 1-2-3	GREEN CODE
EP-1	1K EARPHONE
SW-1	ON OFF SWITCH



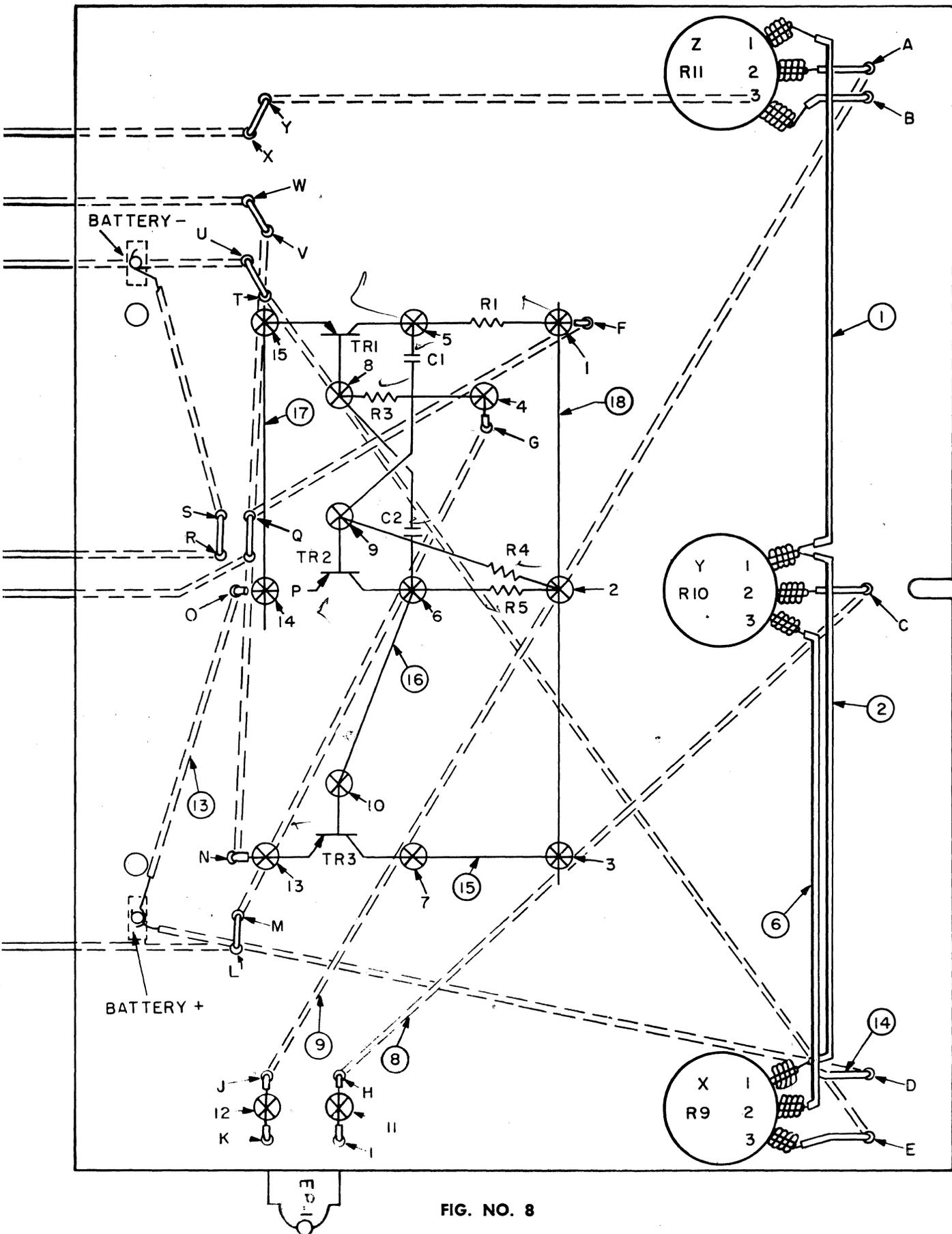


FIG. NO. 8

Step 4.

The three pots you have just installed are the basic working parts of your computer. But numerous other components and a considerable amount of wiring, both on the circuit board and in other parts of your computer, are needed for the computer to function properly.

Let's install the circuit board wiring. First, study the wiring diagram in *Fig. No. 8*. Instructions for installing wiring and components are in the text below. However, you will find it helpful to look at the diagram and see where things go. The diagram also contains handy tables listing all wire connections and components. It's a good idea to check your work against the tables as you go along, to make sure you have made the right connections and installed the right components in the right places.

All wires are ready to use, cut to needed length and with ends stripped of insulation. Different colors are used for easy identification.

Wires are easily installed, too. Use the small

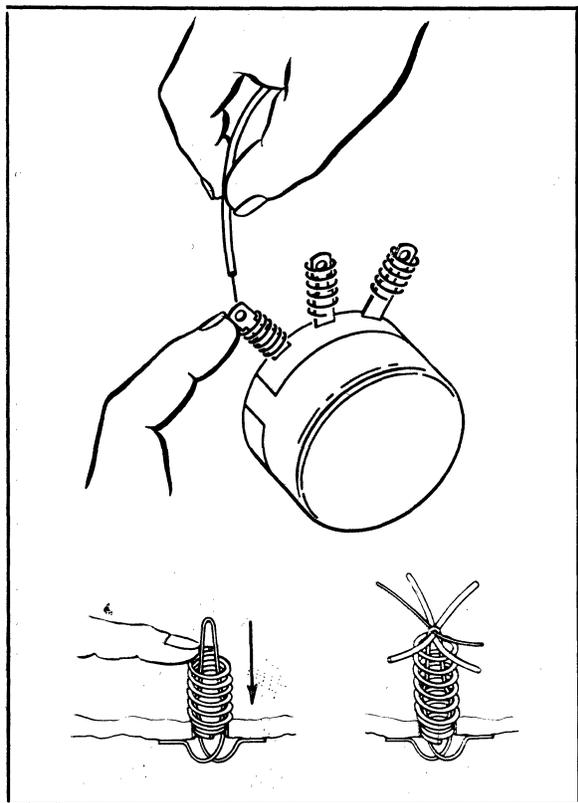


FIG. NO. 9

black spring to connect a wire to a potentiometer or switch terminal. Slip the spring over the terminal and push it down far enough to expose the small hole at the end of the terminal, as in *Fig. No. 9*. Slip the end of the wire through the hole. It will be held tightly when you release the spring.

To insert a wire in a hairpin-and-spring connector, push down the spring and slip the end of the wire through the hairpin loop as in the illustration. Release the spring and the wire will be locked in place. If a wire must be removed, simply push down the spring and pull the wire out. If thick and thin wires must be inserted in the same connector, put the thin wire over the thick one to assure good contact.

Ready to wire the circuit board? Let's go.

—Connect a black wire $7\frac{3}{4}$ inches long from terminal 1 (at left) of pot Z to terminal 1 of pot Y.

—Connect another black wire $7\frac{3}{4}$ inches long from terminal 1 of pot Y to terminal 1 of pot X.

—Connect a black wire $11\frac{3}{4}$ inches long to connector [4]. Run the wire down through hole [G], then under the board to hole [M], up through [M] and down through hole [L]. Leave this end of the wire free. It will be connected during final assembly of the computer.

—Connect a seven-inch red wire to the negative battery terminal by winding it around the screw holding the negative battery clip. Place the wire between the circuit board and the speednut. Loop the wire in the direction shown in *Fig. No. 6* so that it will not come loose when you tighten the screw. Run the wire up through hole [S], then down through [R] leaving the other end of the wire free for the time being, as shown in *Fig. No. 10*.

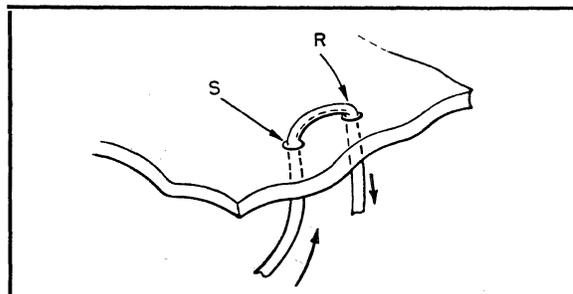


FIG. NO. 10

Join terminal 3 (at the right) of pot Y to terminal 2 (at center) of pot X with a 7 $\frac{3}{4}$ -inch red wire.

Insert the end of a 9 $\frac{1}{2}$ -inch red wire in connector [1]. Pass it down through hole [F], up through hole [Q], and down again through hole [P]. Leave the end disconnected.

Using a brown wire 10 inches long, connect terminal 2 of pot Y and connector [11]. Pass the wire down and up through holes [C] and [H].

Connect a 14 $\frac{1}{2}$ inch brown wire from terminal 2 of pot Z to connector [12]. Run it down through [A] and up through [J].

Connect a 13 $\frac{1}{4}$ -inch orange wire to connector [13]. Run the wire down through hole [N], up through hole [V], and back under the board through hole [W]. Leave the end disconnected.

Connect a 12 $\frac{3}{4}$ -inch blue wire to terminal 3 of pot Z. Run it down through [B], up through [Y] and down through [X]. Leave the end disconnected.

Connect a 17 $\frac{1}{2}$ -inch blue wire to terminal 3 of pot X. Run the wire down through hole [E], up through [T] and down through [U]. Leave the end free.

Two wires are now connected to the positive battery terminal screw, in the same way that you previously connected a wire to the negative battery terminal. One, a 5 $\frac{1}{2}$ -inch yellow wire, comes up through hole [O] and is inserted in connector [14]. The other, a 9 $\frac{3}{4}$ -inch yellow wire, goes from the battery terminal up through hole [D] to terminal 1 of pot X. Be sure to tighten the battery terminal screw holding the two wires.

Join connectors [3] and [7] with a two-inch bare wire; [6] and [10] with a 2 $\frac{1}{2}$ -inch

piece of bare wire; and [14] and [15] with a 3 $\frac{1}{4}$ -inch piece of bare wire.

Run a 6 $\frac{1}{4}$ -inch piece of bare wire from connector [1] through connector [2] to connector [3].

Step 5.

We are now ready to install two of the transistors. Together with other electronic components, the two transistors will generate an electric current that oscillates or surges back and forth many times a second. After being *amplified*, that is made stronger, by a third transistor, this oscillating current will be used to generate a tone in the earphone to guide you in adjusting the answer dial of the computer.

Before proceeding, study the leads on your transistors carefully. They'll look as in *Fig. No. 11*. (It makes no difference which form of transistor you receive in the kit. The two are electrically identical.)

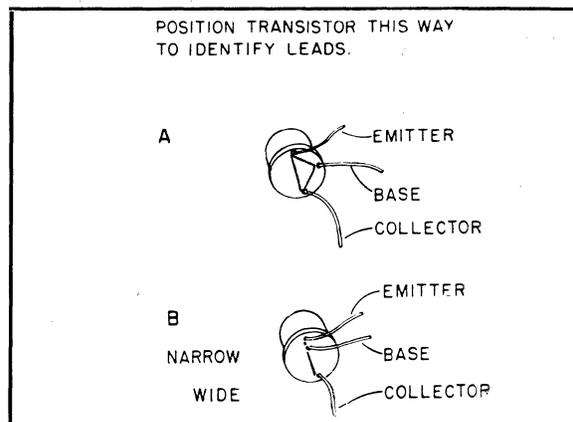


FIG. NO. 11

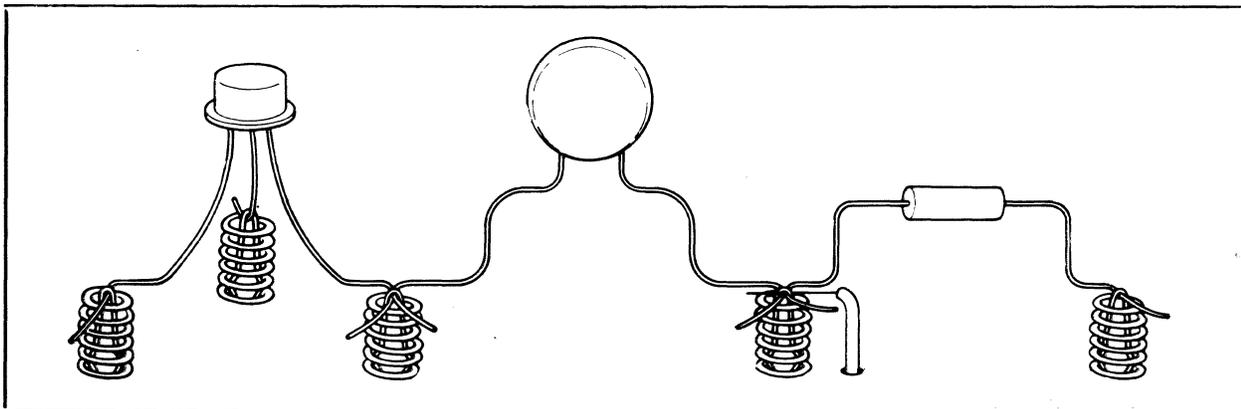


FIG. NO. 12

Note carefully which wire on each transistor is the base, which the collector and which the emitter. Be sure to attach each to the proper connector. *Getting it wrong can damage the transistor as well as prevent your computer from working.* Also use special care in bending the ends of the transistor leads when you connect them. Avoid bending them back and forth. *Fig. No. 12* shows how the leads of transistors and other components should be bent.

~~Connect the~~ first transistor, TR-1, as follows: base to connector [8]; collector to connector [5]; and emitter to connector [15], as in *Fig. No. 13*.

~~Connect another~~ transistor, TR-2, in this way: base to connector [9]; collector to connector [6]; and emitter to connector [14]. (See *Fig. No. 13*.)

Step 6.

Now install the resistors that will work with the two transistors. Your kit includes six fixed resistors. You will need four now. You can pick out the right ones by the three color

bands at one end of each resistor. There is a standard color code by which the value of a resistor can be told at a glance: you can find the code in a radio book if you should like to know more about it. Here are the resistors you now need and the color bands by which you can identify them:

R-1: 1,500 ohms; brown-green-red color bands in that order from the end.

R-3: 10,000 ohms; brown-black-orange.

R-4: 22,000 ohms; red-red-orange.

R-5: 1,500 ohms; brown-green-red.

Connect resistors as in *Fig. No. 13*. R-1 to connectors [1] and [5]; R-3 to [4] and [8]; R-4 to [2] and [9]; and R-5 to [2] and [6].

~~Step 7.~~

Two capacitors are installed next. The two furnished in the kit are identical. One is inserted in connectors [5] and [9] (C-1 in *Fig. No. 14*). The other, C-2, is connected to [8] and [6]. Before installing the capacitors, notice that two of the capacitor leads will cross. To avoid a short circuit, slip a piece of plastic insulating "spaghetti" over each of

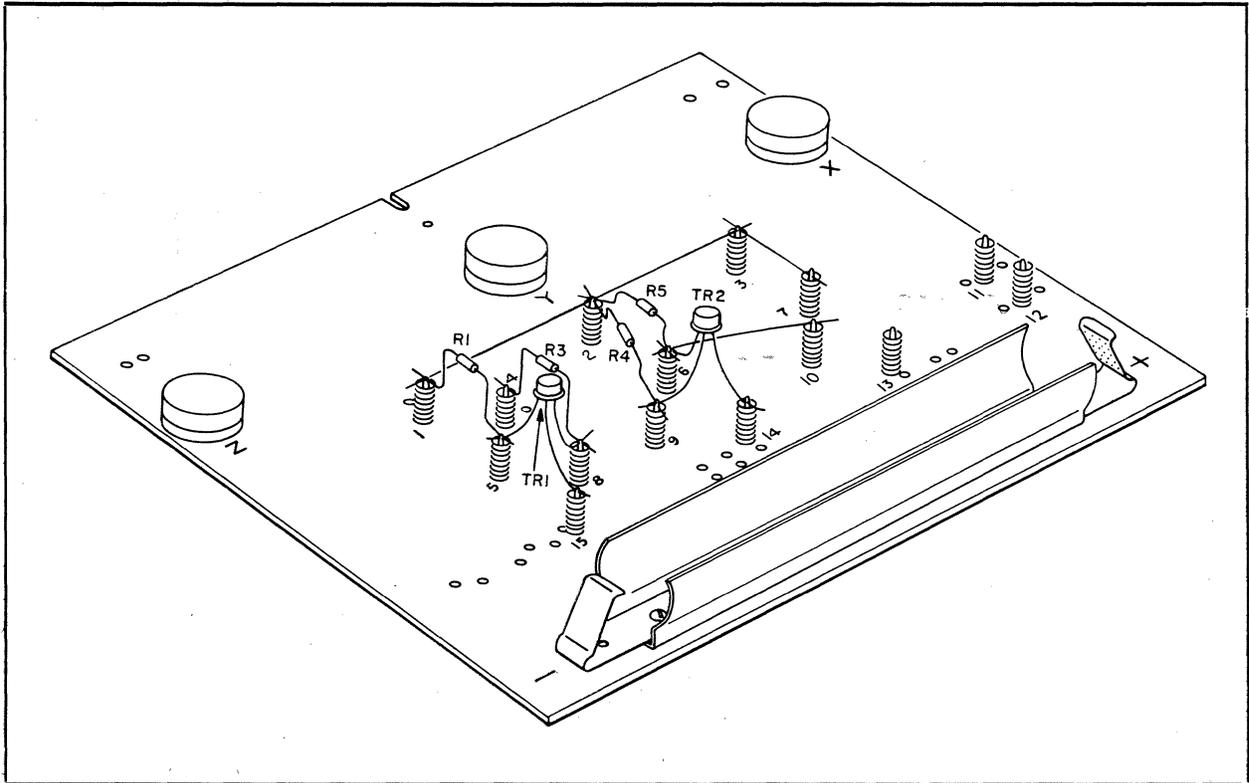


FIG. NO. 13

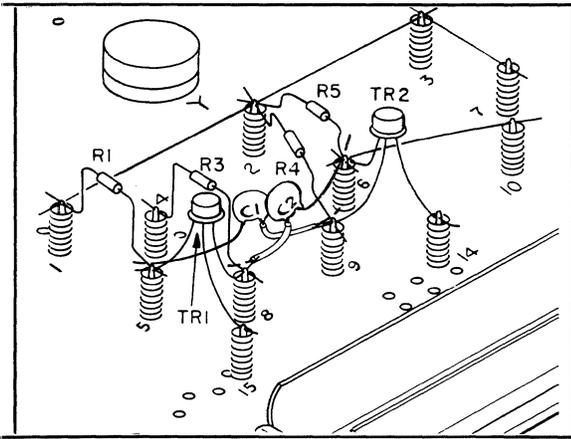


FIG. NO. 14

these wires before they are inserted in the connectors. Two pieces of plastic spaghetti are provided in the kit for this purpose.

Step 8.

The oscillating current generated by the first two transistors is amplified by the third, TR-3. After checking carefully to make sure you have identified the leads correctly, install it as in *Fig. No. 15*: base to connector [10]; collector to [7]; and emitter to [13].

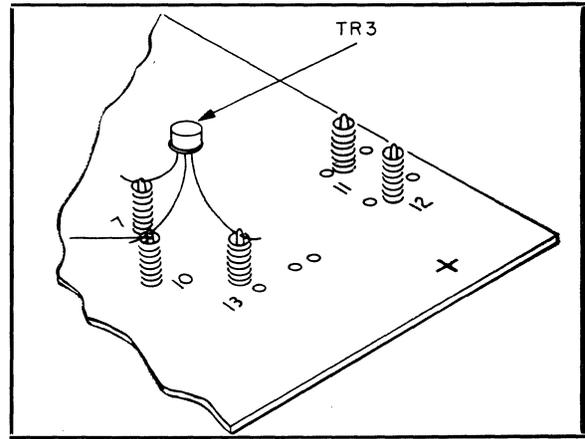


FIG. NO. 15

Step 9.

We are nearly ready to begin coupling the circuit board to the other mounting boards. But first, install the on-off switch in the board marked "TONE" and "CALIBRATE." Insert the switch up through the rectangular hole in the center of the board from the unfinished underside of the board, so that the switch protrudes above the board. (*See Fig. No. 16.*) Secure with two screws and small flat speed-nuts. Insert the screws from the top of the board.

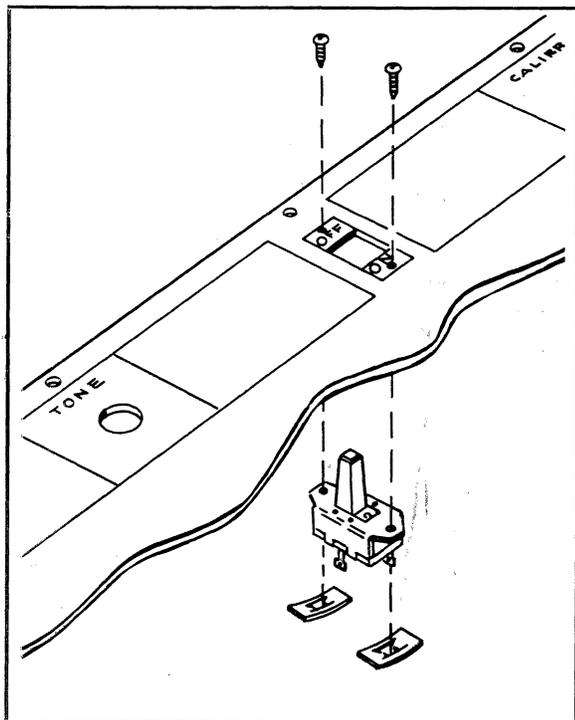


FIG. NO. 16

Step 10.

Eight brackets are provided in the kit for joining the mounting boards and installing them in the finished computer. Four are shaped somewhat like the letter Z and will be called Z brackets. (*See Fig. No. 17.*)

Two other brackets, with five bends and four holes each, look something like elongated W's. These will be referred to as W brackets.

Of the two remaining brackets, one is small, the other one, much longer. They will be referred to as the small center bracket and the large center bracket.

You will also find seven U-nuts. These are small pieces of metal folded in a U shape, with a round hole on one side and a split hole on the other. This type of nut does not need to be held while a screw is inserted into it. U-nuts are handy for attaching hardware in places where you could not hold a nut with your fingers.

Attach a U-nut to each Z bracket by slipping the nut over the end of the bracket, as in

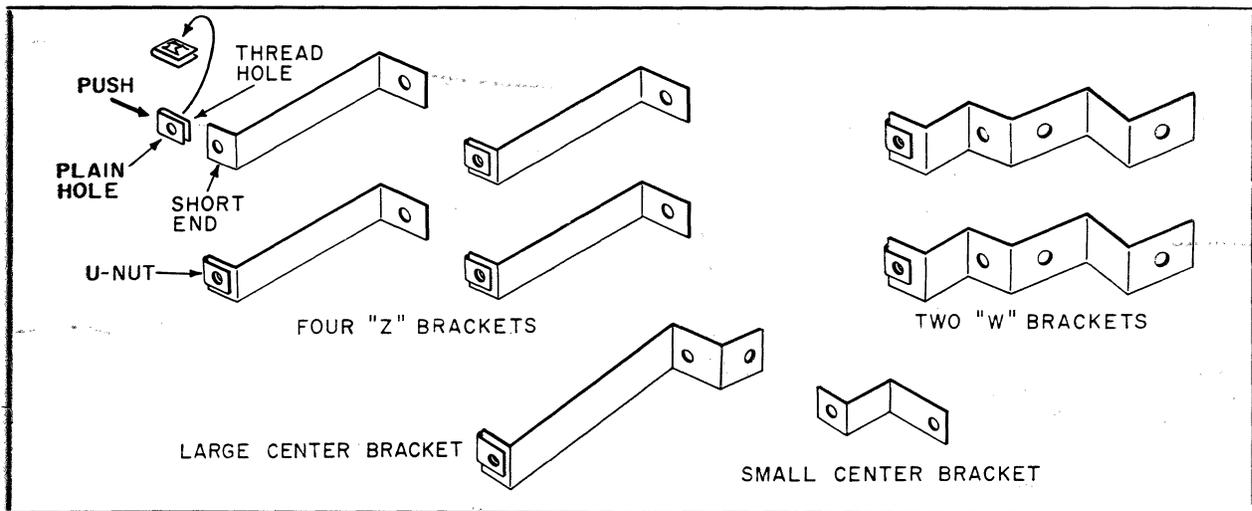


FIG. NO. 17

Fig. No. 17. Make sure the hole in the nut coincides with the hole in the bracket. Notice that the two end flanges of the Z brackets are not equal in length. The U-nuts go on the short ends. Put a U-nut on the short end of each W bracket, as in the illustration, and also on the short end of the large center bracket. In all cases, the split side of the nut should be toward the main part of the bracket rather than away from it.

~~Step 11.~~

Mount a pair of Z brackets on the back of the vertical board that will support the computer dials, as in *Fig. No. 18*. Use the ends that do *not* have U-nuts. The U-nut ends of the brackets should point toward the upper edge of the board. Insert screws from the front of the board. Secure them with speednuts.

~~Step 12.~~

Now install the tone and calibration potentiometers (marked 200 and 200K) that were laid aside back in Step 3. Insert one through the large hole in each W bracket, as in *Fig. No. 19*. Be sure to insert the pots so that the shafts go through the brackets and the terminals point in the direction shown. Secure with large nuts. Tighten so that the pots do not slip when their shafts are turned.

~~Step 13.~~

Mount the W brackets on the vertical dial board, as in *Fig. No. 18*. Since one bracket has

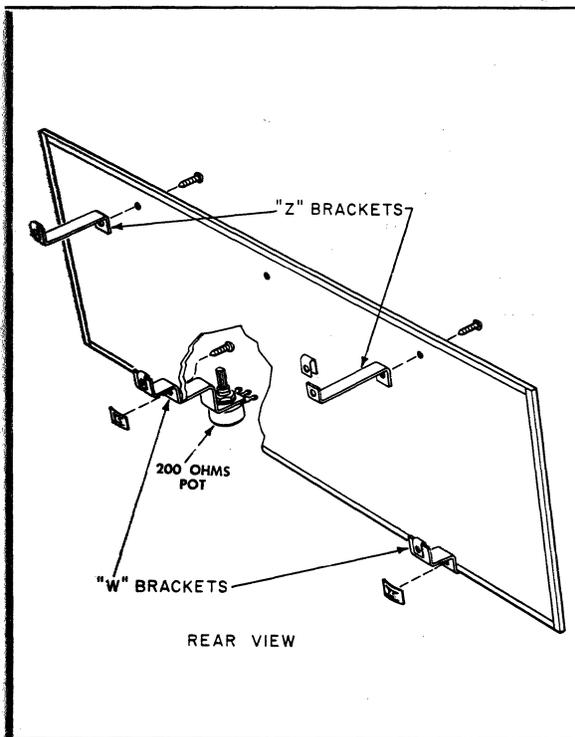


FIG. NO. 18

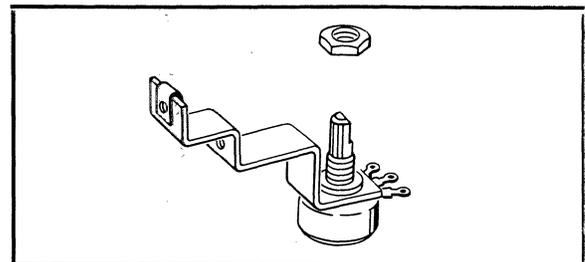


FIG. NO. 19

the calibrate pot (200), and the other the tone control pot (200K), be sure to get each bracket and pot where it belongs (see diagram). Be sure also that the shafts of the pots point up, and that you attach the brackets to the board through the correct holes in the brackets. Secure with screws and speednuts.

Now attach the board with the on-off switch. This will be the horizontal control panel of the computer and it will rest on the W brackets.

Set the horizontal control panel on the W

brackets so that the shafts of the pots on the brackets come up through the large holes in the horizontal board, as in *Fig. No. 20*. Notice now a small hole immediately above the large holes in the horizontal board. These correspond to holes in the W brackets. Line up the small holes in the horizontal board with the holes in the brackets. Insert screws down through the horizontal board and the brackets. Secure with speednuts on the underside of the brackets. (See illustration.)

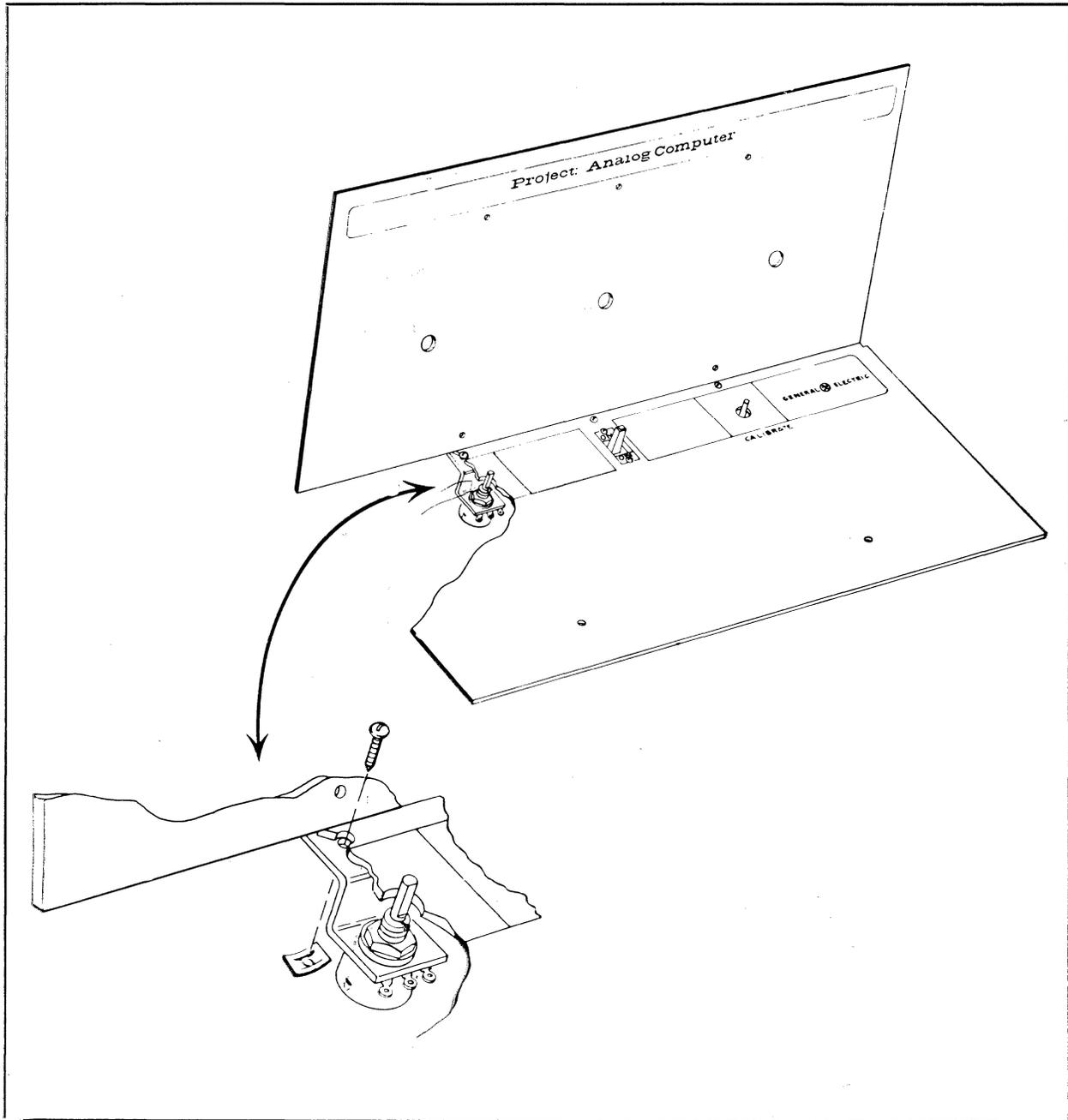


FIG. NO. 20

Step 14.

Mount the large center bracket to the two boards you have just joined. Holes in one end of the bracket will match holes near the switch on the horizontal and vertical boards, as in *Fig. No. 21*. Be sure the bracket points perpendicularly away from the horizontal board.

Step 15.

Next step is joining the circuit board to the horizontal and dial boards.

Mount the small center bracket on the rough side of the circuit board, as in *Fig. No.*

21. The bracket goes on the rough side of the circuit board at the U-shaped slot at the upper edge of the board, as shown in the drawing detail. Make sure that the free end of the bracket points upward as the circuit board stands up. Fasten with a screw and speednut.

Now place the circuit board in position behind the dial board, so that the shafts of the three pots protrude through the three holes in the vertical board. Push the three large dial knobs on to the potentiometer shafts.

At this point the board is held in place only by the dial knobs. It must be attached more securely by means of the three brackets

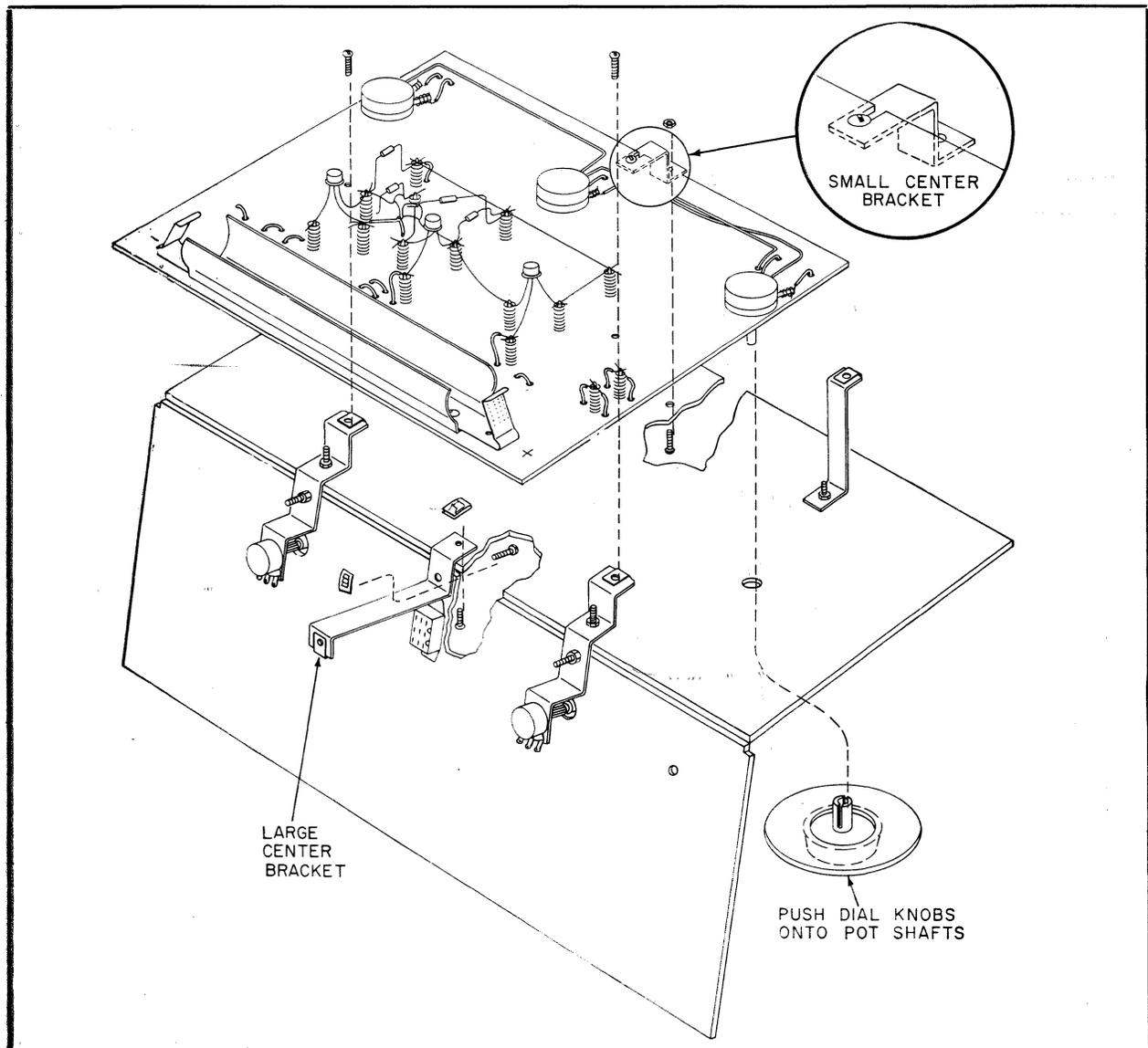


FIG. NO. 21

that just fit between the circuit board and the vertical dial board. As indicated in *Fig. No. 21*, these are the small center bracket you just mounted on the circuit board, and the rear bends of the W brackets. (Do not attempt to use Z brackets on the vertical dial board for attaching the circuit board. They do not fit onto the circuit board.) Fasten the unconnected end of the small center bracket to the dial board with a screw and speednut. If the bracket and board do not line up properly, wiggle the board a little. Now fasten the circuit board to each W bracket with a screw; you will not need any nuts as these ends of the W brackets should already have U-nuts on them. The ends of the W brackets go on the side of the circuit board facing the front of the computer. (See *Fig. No. 21*.)

Step 16.

Slip the knobs on the shafts of the tone and calibrate pots sticking up through the horizontal board.

Step 17.

Find the two remaining Z brackets with

their U-nuts. Mount them in the bottom half of the kit box, as in *Fig. No. 22*, by inserting a screw from underneath the box. The upper bends in the bracket should point towards the back of the box.

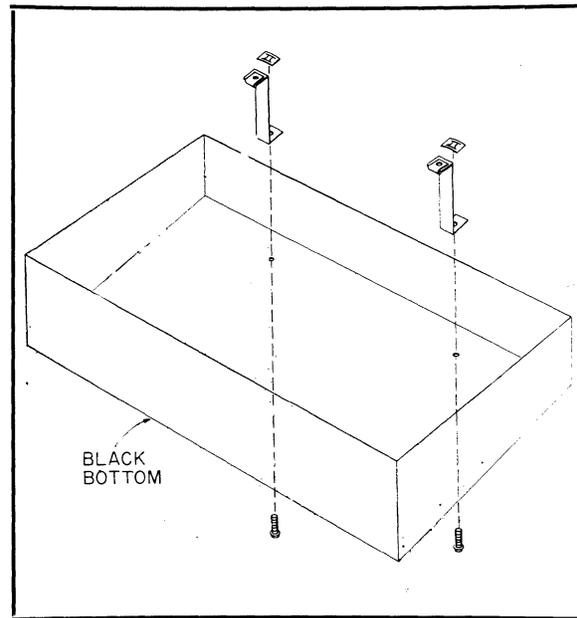


FIG. NO. 22

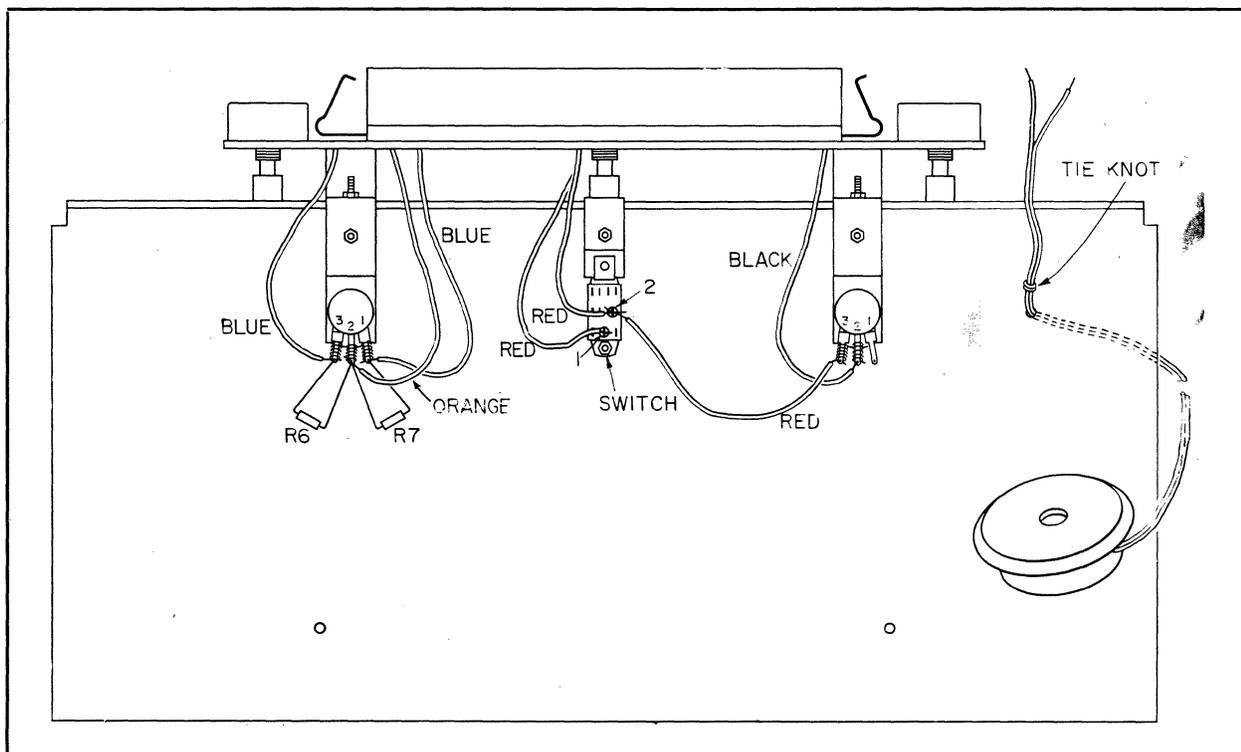


FIG. NO. 23

Step 18.

You are now ready to finish wiring your computer.

Turn the computer assembly over so that the underside of the horizontal board faces you, as in *Fig. No. 23*.

Six of the wires previously connected to the circuit board have a free end. The connections to be made now are listed below, from left to right as you face the underside of the horizontal board and as in *Fig. No. 23*. Make sure you have the proper wire before making any connections.

~~The blue wire~~, which you connected to the terminal 3 of Pot Z and passed through holes [B], [Y] and [X], should be attached to terminal 3 (the left hand terminal) of the 200-ohm pot, the calibrator.

~~The orange wire~~, in connector [13] and passing through holes [N], [V] and [W], should be connected to terminal 2 (center terminal) of the calibrate pot.

~~The blue wire~~, connected to terminal 3 of pot X and passed through holes [E], [T] and [U], should be connected to terminal 1 of the calibrate pot.

~~The red wire from connector [1]~~ and passing through holes [F], [Q] and [P], should go to terminal 2 (center terminal) of the on-off switch.

~~Another red wire~~, coming from the battery through holes [S] and [R], should be connected to switch terminal 1, the terminal farthest from the vertical board.

~~The last free wire~~ is black and comes from connector [4] and passed through holes [G], [M] and [L]. Attach it to terminal 2 of the 200K pot, the tone control.

Now connect a 6-inch red wire — the only remaining piece of wire in the kit — from terminal 3 of the tone control pot to terminal 2 of the switch. (Terminal 1 of the tone control pot is not used.)

~~Finally~~, attach the two last resistors, R-6 and R-7 (both 33 ohms; orange-orange-black) between terminal 1 and terminal 2, and terminal 2 and terminal 3 of the calibration pot. (See *Fig. No. 23*.)

~~Step 19.~~

Connect the earphone leads to the circuit board. First, pass the leads from the top of

the horizontal board down through the hole at the left of the board (at the right as in *Fig. No. 23*). Pass five or six inches of the leads through the holes and make a loose knot below the board so that a slight pull on the earphone will not disconnect the leads. Now pass the leads through holes [I] and [K] in the circuit board and attach them to connectors [11] and [12]. Complete the earphone installation by locking the headband into the holes in the back of the earphone, as in *Fig. No. 24*.

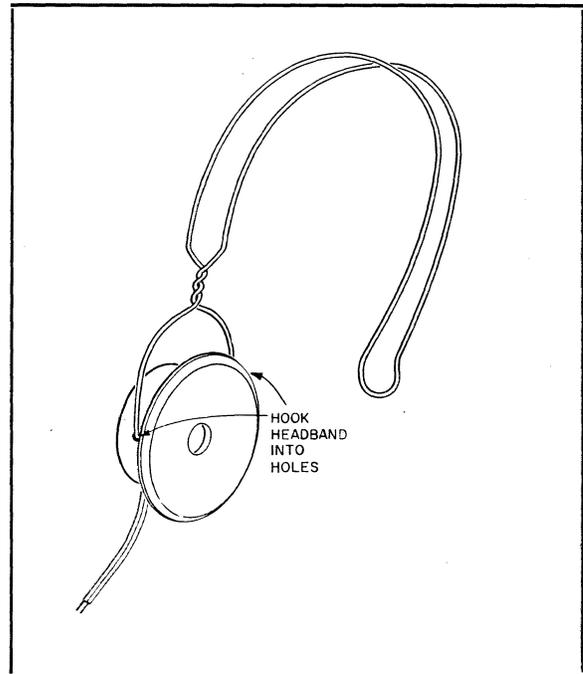


FIG NO. 24

~~Step 20.~~

The time has come to install batteries. First, make sure the on-off switch is in the off position. Then check the wiring and installation of all components, especially that done since you completed and checked the circuit board.

When you are sure everything has been properly done, insert the four batteries in the battery holder, with the positive (button) ends of the batteries toward the positive mark on the circuit board as in *Fig. No. 25*. Take care to install them correctly. Incorrect mounting can damage components like the transistors as well as prevent the computer from working.

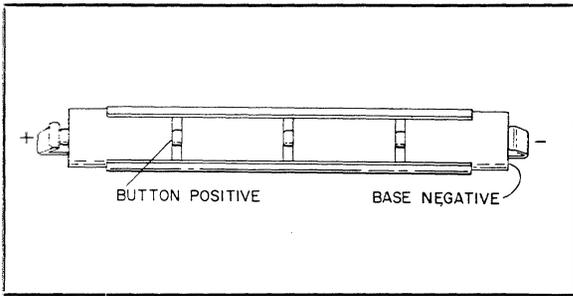


FIG. NO. 25

Step 21:

To make sure that the set is properly wired, put on the earphone and turn the switch to the *on* position. You should hear a tone. Turn the knob on the calibration potentiometer, and the tone should increase and decrease in volume. Turn the knob of the tone control and the pitch of the tone should change. Turn the pot knobs of potentiometers X, Y and Z, and the volume of the tone should again increase or decrease. If all of these

tests work, your computer is probably properly wired. Otherwise, go over what you have done step by step, checking each of the connections and components for proper wiring. Check also all the wire connections, moving them slightly to make sure that they are tightly held. Check the distribution of the transistor leads. You can verify the position of the leads without removing the transistors, by looking at the points of origin of each lead and making a brief diagram for each one of them. Then compare this diagram to the one in *Fig. No. 11.*

Step 22.

Everything worked well? You are ready to install your computer in a handsome console fashioned from the clear and black plastic halves of the box your kit came packed in.

Set the black plastic bottom of the box before you. Stand the clear top, open side facing you, at the back inside the bottom of the box. Lift the computer assembly and slide

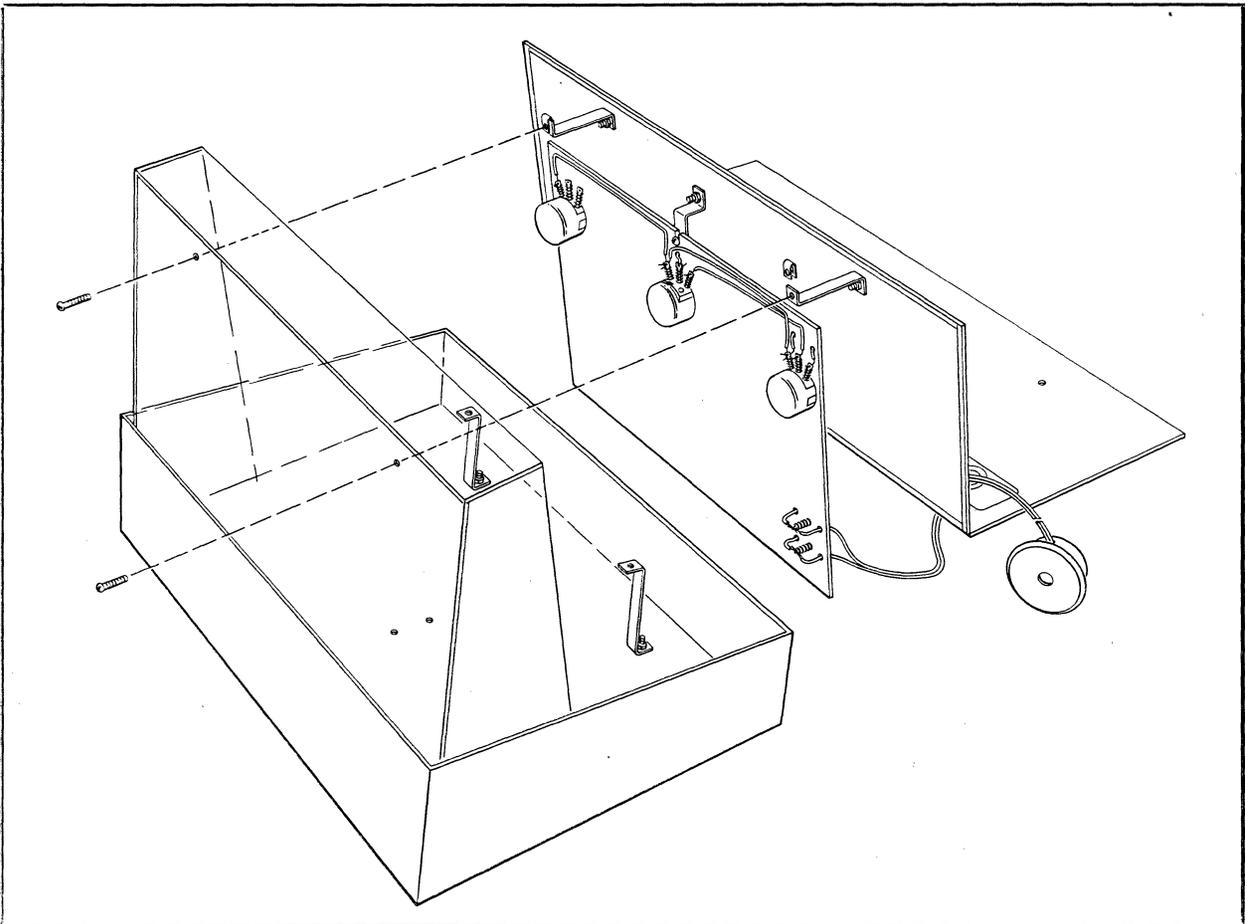


FIG. NO. 26

it back into the cabinet, as in *Fig. No. 26*. The vertical dial board should fit, facing you, into the opening of the clear top. The horizontal board should rest on the brackets in the bottom of the cabinet.

From the back of the standing set insert two screws into the two Z brackets mounted on the vertical dial board. If the holes do not quite correspond, move the vertical board right and left until the holes are aligned. Don't tighten the screws yet. If the U-nuts are loose and out of place, you may wish to tape them in place while you complete the assembly.

Tip the set back carefully, as in *Fig. No. 27*, and drive a screw through the center hole on the underside of the cabinet, making sure the screw fits into the U-nut on the large central bracket, which you cannot see. If the two holes do not quite correspond, use the switch to move the horizontal board until they are lined up.

Stand the unit straight. At the top of the horizontal board, there are two holes. (See *Fig. No. 28*.) Through these, insert screws downward into the two remaining brackets,

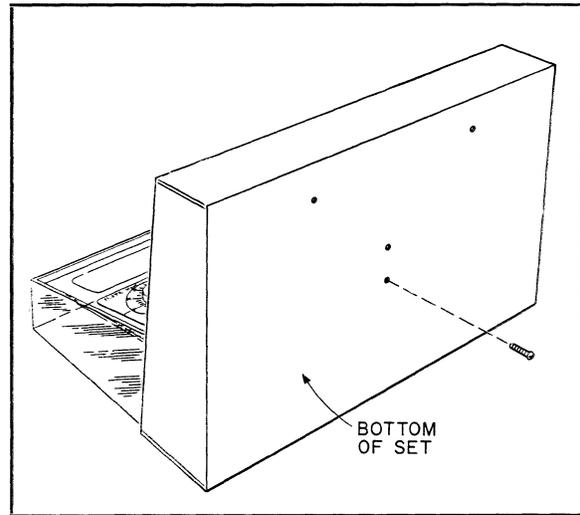


FIG. NO. 27

making sure the screws are in the U-nuts on the brackets. When you have finished, go over the outside screws and tighten them up.

Congratulations! You've built an analog computer. To see how it works, turn to the next page. To put it to work on mathematical problems, turn to Page 25.

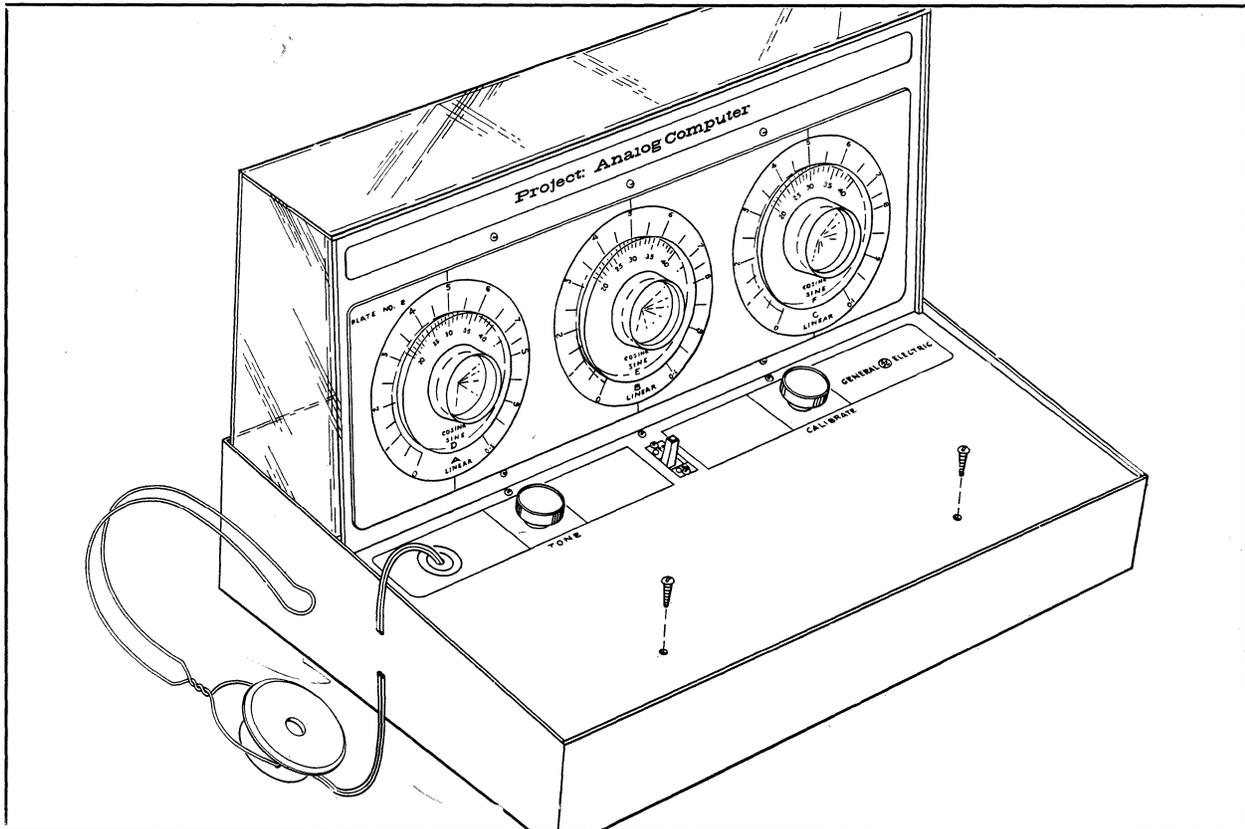


FIG. NO. 28

PART 4

HOW YOUR COMPUTER WORKS

Now that you have completed your computer, you must be impatient to put it through a trial run. If so, try a few of the problems outlined in the next section. But then come back to this section and read this brief explanation of how your computer works.

As mentioned in Part 1, "What You Will Do with Your Kit," on Page 4, there are two types of computer, digital and analog. Digital computers compute by counting. An electronic digital computer counts pulses of electricity.

Analog computers, such as yours, operate on a different principle. They compare physical quantities. In the case of your computer and many analog computers built today, electric currents are compared to physical happenings, such as the flow of water and the force of rocket engines.

What happens is this: An electric current is divided into two parts. One part is for the problem. The other represents the answer. The problem part is put through steps corresponding to the multiplications and other mathematical operations called for in the problem. The answer current is then adjusted to match the problem current. The value of the adjusted current gives the answer. It can be read off on a scale.

Let's get specific. Let's see how *your* computer works and what happens when you multiply two numbers.

First of all, your computer has two basic sections. The three pots X, Y and Z form one. It has to do with the computation. Most of the rest of the computer forms the other section. The latter has to do with reading answers more accurately and easily.

Let's look at the pots. Current coming from the batteries is divided into two parts. One goes to the pots into which the problem is transcribed. The other goes to the answer pot. The problem is set on two pots (by means of the scale dials) and the third is manipulated so that the two sub-currents are balanced, and no electricity flows from the problem to the answer part or vice versa. Then the answer corresponds to the problem.

How do potentiometers adjust current to correspond to problems and answers? A poten-

tiometer is a resistance device. It reduces the *voltage* or pressure of a current. *Fig. No. 29* is a diagram of the type of potentiometer used for pots X, Y and Z. A thin high-resistance wire is wound around the arc from A to C, and the arm B can swing around the arc from A to C. When the arm is all the way to the right, there is very little resistance between A and B. As a result, there is maximum current flow and little loss of voltage. As the arm is moved away from A, the current must pass through more and more of the wire, the resistance increases, the voltage drops and less current flows through.

Now look at *Fig. No.30*, showing three potentiometers as they might be set to carry out a simple problem, the multiplication of $\frac{1}{2}$ by $\frac{1}{2}$.

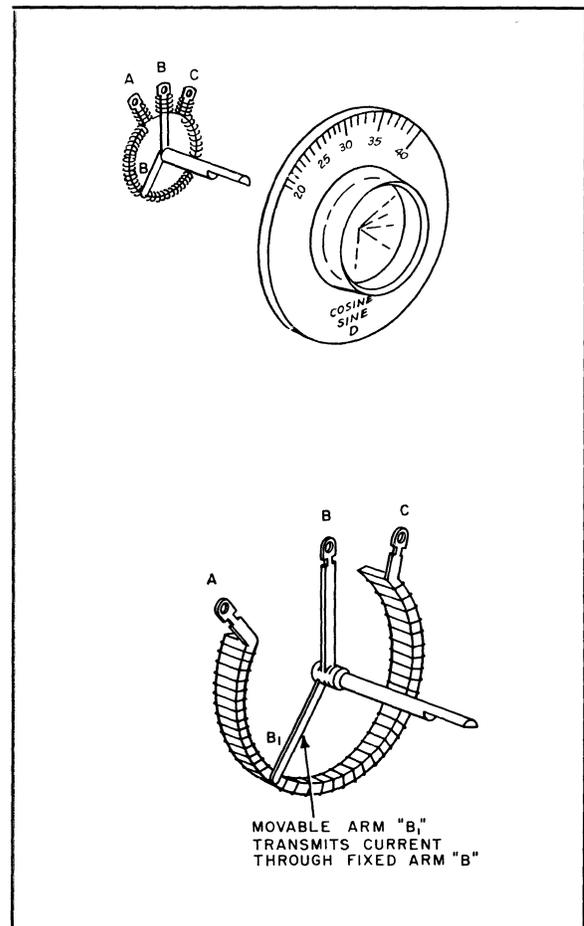


FIG. NO. 29

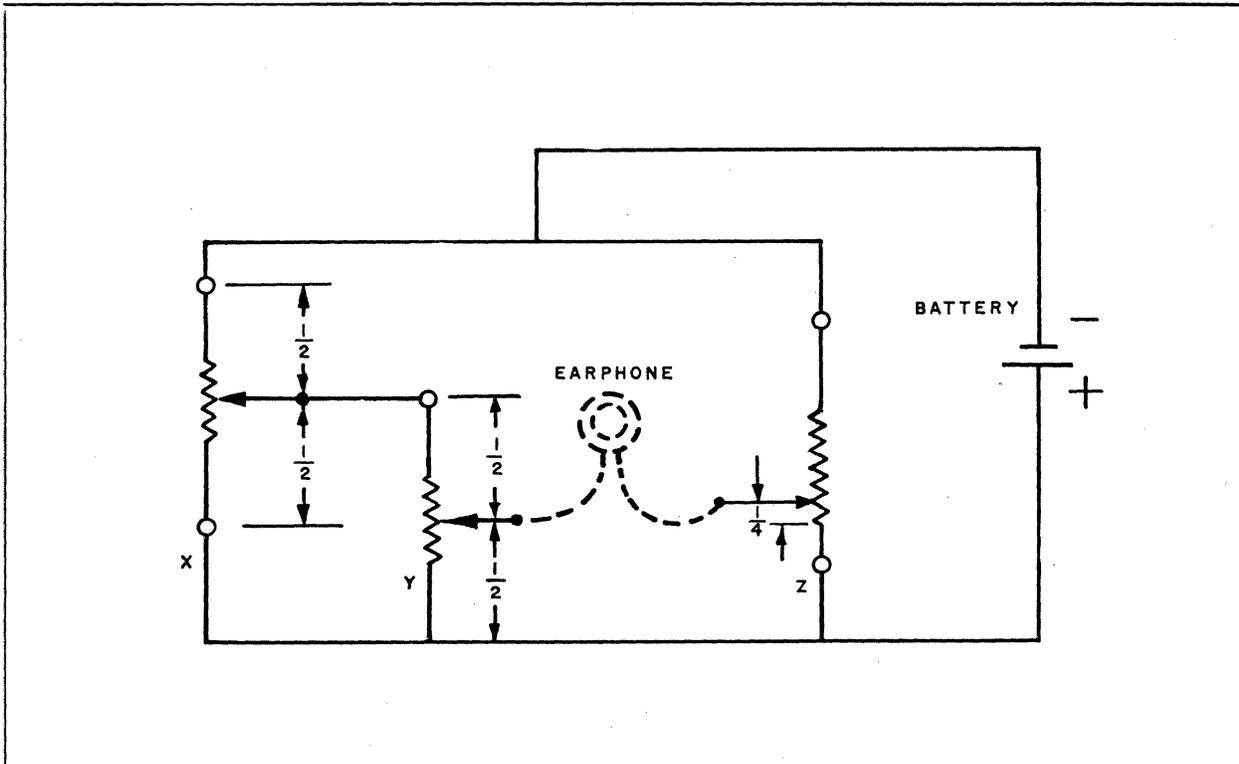


FIG. NO. 30

Notice first that part of the current from the batteries goes to pot X and then to pot Y, while the other part goes to pot Z.

The arm of pot X is set so that the current to pot Y must first flow through *half* the resistance wire in pot X. This reduces the voltage supplied to pot Y — which receives current only through pot X — by half. But pot Y is also set so that the current must flow through *half* the resistance wire. So the voltage is halved again. Half of a half is one-quarter. In effect, you have multiplied $\frac{1}{2}$ by $\frac{1}{2}$.

So a current with one-quarter of its initial voltage emerges from pot Y. How can you measure it and determine the answer to your mathematical problem? One way is to balance it against a current whose voltage you can control. This is what you do in your computer. By turning the knob on dial Z, you adjust the voltage of the current coming from pot Z until it is equal to the voltage coming from pot Y. You then read the setting of dial Z for your answer.

An analog computer could be built with nothing but three pots and a voltmeter or other device to tell when the currents from pot Y and pot Z were of equal voltage. Your computer, however, has a more sensitive,

easier-to-use arrangement. The current to the pots is fed through a pair of transistors wired up in what computer men call a “flip-flop” and radio men term a *multivibrator*. When the on-off switch is first turned on, the current to one transistor is larger than the current to the other. This starts a current see-sawing back and forth between the two transistors. The see-saw current will continue as long as the currents from the pots are out of balance.

Now, in your computer, the flip-flop is arranged so that the see-saw current surges back and forth many hundreds of times a second. Further, the see-saw current is amplified or made stronger by a third transistor, and is then fed into an earphone. In the earphone, it causes a diaphragm to vibrate and generate a tone which you can hear. So you use your ear to tell when the currents from pots Y and Z are in balance and you can read the answer on dial Z. When the pot currents are in balance and no current flows through the earphone circuit, there is no tone in the earphone. You find your answer by adjusting the answer pot until you hear nothing at all in the earphone. In the language of science, you “turn the dial to null.”

PART 5

PUTTING YOUR COMPUTER TO WORK

In putting your computer to work, there are two essential preliminary steps. You must calibrate it, that is, adjust it to give correct answers. And you must install a Scale Plate appropriate to the problem you wish to solve. In addition, you may wish to adjust the tone control so that the tone generated by the earphone is pleasing to your ear. All three tasks are simple.

Calibration. Install any scale plate you wish on the dial board. Simply remove the scale knobs, slip the scale plate over the three pot shafts and put the knobs back.

Turn the on-off switch to on. Set dial X at .6 on Scale A (the outside scale). Set dial Y at .7 on Scale B. Set dial Z at .42 on Scale C. Listen in the earphone. Turn the calibrate knob until you hear no sound. The currents are then properly divided between the problem and answer portions of the computer, and the computer is calibrated for proper operation. The computer need not be adjusted between problems, but you should re-calibrate it each time you sit down to work with it. If you cannot calibrate the computer this way, remove the two 33-ohm resistors from the calibrate pot, and try calibrating again.

Tone Control. The tone control changes the tone or pitch of the sound you generated in the earphone, not the volume or loudness. To adjust the tone, simply turn the knob until the earphone generates a satisfactory tone.

Scale Plates and Memory Boards. To solve problems of different kinds, you must make use of a variety of dial scales. These are printed on three scale plates. Memory boards containing a great variety of formulas and other aids to computation are printed on the reverse side of the scale plates. The scale plates are so arranged that when you install Scale Plate No. 1 in your computer, for instance, the accompanying memory board will be on the reverse side of one of the *other* scale plates.

The memory boards and the manual indicate which scales and which scale plates are needed to solve different types of problems.

As mentioned above, scale plates are simply changed by removing the scale knobs from the pot shafts. Then place the appropriate memory board on the horizontal control panel in front of you and go to work.

One thing more: The memory boards contain many more formulas than can be discussed in the manual. The boards are designed to serve as a handy "formula dictionary" to enable you to solve the greatest variety of problems. After you have worked a few of the formulas on each board, you will have no trouble doing others on your own.

MULTIPLICATION

As you may have noticed, you have already carried out a multiplication. To calibrate your computer, you multiplied .6 by .7 and adjusted the calibrate knob to give the known result, .42. Now let us go about the general rules for multiplication with your instrument. Multiplication is carried out with Scales A, B and C. You will find these the outer scales on all three Scale Plates.

Multiplication is performed by setting one of the numbers to be multiplied on Scale A and the other on Scale B. The answer is read on Scale C.

Notice that the three scales are numbered only from 0 to 1.0. This means that a bit of number juggling will have to be done to deal with numbers larger than 1.0.

More on that in a moment. Let's first try a pair of numbers that can be handled without juggling. Multiply $.8 \times .4$.

Set the pointer of dial X to .8 on Scale A. Set dial Y to .4 on Scale B. Now turn the pointer of dial Z until you hear no sound in the earphone — in other words, until the voltage from pot Z balances the voltage from pot Y and no tone current reaches the earphone. (See "How Your Computer Works" on Page 23.) When you have thus turned the dial to "null," read the pointer setting on Scale C. It should be .32.

Now for numbers bigger than 1.0. These are multiplied by putting them into a form that fits the scales. We write such numbers as *powers*.

A power is a form of multiplication. 4×4 , for example, can be written 4^2 , which is read as 4 to the second power. The number on the upper right is the exponent. It tells how many times a number must be multiplied by itself. Thus, $4^3 = 4 \times 4 \times 4 = 64$.

Any number can be written as a power if we go about it in the right way. One way is to write it as a power of 10. For instance, $10^2 = 10 \times 10 = 100$. But what about 250? That's easy: $2.5 \times 10^2 = 2.5 \times 10 \times 10$, which, if you multiply it out, is 250. Now what about 27? That's $2.7 \times 10^1 = 2.7 \times 10 = 27$. And 5? That's $.5 \times 10^1 = .5 \times 10 = 5$.

Notice in that last example that .5 is a number that will fit on the scale. So, to multiply large numbers, change them into a form such that the first part is between 0 and 1.0. Actually, there is an easy rule for doing this. Suppose you want to put 320 in power form. 320 has three digits. Move the decimal point three digits to the left, making it .320 or .32, and put a 3 as the exponent of 10. Thus, $320 = .32 \times 10^3 = .32 \times 10 \times 10 \times 10 = 320$.

Now let us multiply 320×4200 . $320 = .32 \times 10^3$; $4200 = .42 \times 10^4$. Set dial X to .32 and dial Y to .42. When you turn the third dial to null, the pointer will be at about .134.

However, you're not quite finished. The answer is actually $.134 \times 10$ to some power. But what power? That's easiest of all. Merely add the exponents from $.32 \times 10^3$ and $.42 \times 10^4$. $3 + 4 = 7$. The answer is $.134 \times 10^7$. To convert this back to an ordinary number, simply move the decimal point as many places to the *right* as you have powers of 10. In this case, the decimal point must be moved seven places to the right: $.134 \times 10^7 = 1,340,000$.

PROBLEMS

(Answers to problem are on Page 38)

1. 23×77
2. 438×519

DIVISION

Division is the opposite of multiplication, both when you do it with pencil and paper and on the computer. On the computer, though, it's easier. The same dials are used as in multiplication. However, the number to be divided (the dividend) is set on scale C and

the dividing number (the divisor) on scale B, and your answer (the quotient) is read on scale A.

For example, divide .32 by .8 ($.32 \div .8$). Set dial Z on .32 and dial Y on .8. Turn dial X to null, and read the answer on scale A: .4. You can also use scale A for the dividing number, and read the quotient on scale B. But dial Z must always be used for the number being divided.

If any of the numbers you are working with are too large to fit on a scale, rewrite them as powers as you did for multiplication. But in division, powers are subtracted instead of being added. For instance, $100,000 \div 1,000 = 10^5 \div 10^3 = 10^{5-3} = 10^2 = 100$. To divide 498,000 by 623, rewrite the numbers: $.498 \times 10^6 \div .623 \times 10^3$. Set .498 on scale C and .623 on scale B. Turning dial X to null, read the preliminary answer on scale A: .8. Now subtract the powers. $10^6 - 10^3 = 10^3$. Your final answer is $.8 \times 10^3$, or 800.

PROBLEMS

3. $29 \div .81$
4. $95 \div .48$
5. $211,000 \div 137$

DEALING WITH VERY SMALL NUMBERS

Sometimes, the numbers you must deal with are very small. Such numbers are easily rewritten and handled on your computer as powers, but the powers become negative.

One number familiar to modern physicists is:

.000 000 000 000 000 000 000 000 06

This is the mass in ounces of an atom of hydrogen. It would be cumbersome to write out the 25 zeros every time, so the number is simply expressed as:

$$6 \times 10^{-26}$$

The rule here is: The negative exponent is one more than the number of zeros in front of the first significant figure.

To adapt 6×10^{-26} to your computer scales, change it to $.6 \times 10^{-25}$. So for your computer scales, the rule on small numbers is even simpler: The negative exponent and the number of zeros between the decimal point and the first significant figure are the same. For instance, $.00083 = .83 \times 10^{-3}$. You then multiply out or divide such numbers in the ordinary way, remembering only to add and subtract

exponents properly. Thus, $.008 \times .04 = (.8 \times 10^{-2}) \times (.4 \times 10^{-1}) = .32 \times 10^{-3} = .00032$. Or for division: $.0004 \div .08 = (.4 \times 10^{-3}) \div (.8 \times 10^{-1}) = .5 \times 10^{-2} = .005$.

Negative powers may also arise when you divide large whole numbers. For example, divide 400 by 80,000. Rewritten in power form, this is $(.4 \times 10^3) \div (.8 \times 10^5) = .5 \times 10^{-2} = .005$, the correct answer. Just remember: with the scales on your computer, write down a number of zeros before the first significant figure equal to the negative exponent.

PROBLEMS

6. $.000000481 \times .000052$
7. $.00047 \div .063$
8. $232 \div 1,530,000$

FORMULAS AND PROBLEM SOLVING

With the aid of the memory boards and A, B and C scales on your computer, you can quickly solve a wide variety of interesting problems.

Are you a baseball fan? You can use the computer to figure winning percentages. Simply enter the total number of games played on Scale A of dial X, and the number of games won on Scale C (dial Z); the winning percentage can be read on Scale B (dial Y). Or batting averages: Enter the total times at bat on Scale A and the number of hits on Scale C; again, the average can be read on Scale B.

Here is a very different problem:

Problem 9. How many miles away is Alpha Centauri, the star closest to our solar system? Alpha Centauri is 4.3 light years away. The velocity of light is 186,000 (or $.186 \times 10^6$) miles per second.

The solution of this problem and many others like it is simply a series of multiplications. First, figure out how many seconds there are in a year, then how many miles light travels in a year and finally how many in 4.3 light years. And here's a handy feature of your computer that will speed your work: At the end of each multiplication, when you read the answer on Scale C, transfer it immediately to scale A for the next multiplication. In that way, you can avoid having to write down any of the intermediate answers.

Many problems can be solved by means of the mathematical "shorthand" expressions called formulas. Some are in the form of the equation $X \cdot Y = Z$, where the dot stands for the multiplication sign. The equation is also often written $XY = Z$ without either a dot or the multiplication sign. Some formulas look like $\frac{A}{B} = C$, where C equals A divided by B. Some are a combination of these two types of simple equations.

Formulas of these types can be solved on the A, B and C scales. Simply substitute the numbers given in the problems for the right letters in the formula and carry out the indicated multiplication. (Later, you will be able to solve problems involving several multiplications and divisions even faster with the help of Scale Plate No. 3).

A large number of formulas as well as conversion factors (for converting miles per hour to feet per minute, horsepower to watts, and so forth) and other aids to computation are printed on the memory boards. Let's work a few of the formulas of the $XY = Z$ and $\frac{A}{B} = C$ types.

The formula for the area of a square or of a rectangle is AB , where A is the length of one of the sides and B, the length of the other. A rectangle 8 feet long and 5 feet wide will have an area of $8 \times 5 = 40$ square feet. Try this:

Problem 10. Which is larger, the Principality of Monaco or Central Park in New York? The Principality of Monaco has an area of half a square mile. Central Park is approximately 13,300 feet long, 2,700 feet wide.

Find the formulas for the volume of a pyramid and of a rectangular structure like a building. Then try these:

Problem 11. What is the volume of Egypt's Cheops pyramid, the largest one in the world? Its base is a square with sides 756 feet long, and the pyramid is 450 feet tall.

Problem 12. Compare the volume of Cheops' pyramid with the volume of the tallest modern building, the Empire State Building in New York. The latter has a base 425 feet by 197 feet, and is 1,250 feet tall (not counting the television tower, which is 222 feet tall, and

without allowing for the setback of the upper stories).

For the fun of it, you might want to find the answer to:

Problem 13. How many people, tightly packed, would the Empire State Building hold? Assume that an average person occupies a volume of three cubic feet. The population of the world is about 3×10^9 . What percentage of the world's people could fit into the Empire State Building?

To solve the next problems, you must become familiar with π (called "Pi") the number of times a circle's diameter will fit into the circle's circumference. Pi is an "irrational" number which cannot be calculated exactly. Use a value of 3.14 for π in working with the formulas for these problems:

Problem 14. What is the volume of a cone 3 feet high and having a base with a radius of 2 feet?

Problem 15. Given a cone 6 feet high and with a base having a radius of 1.5 feet, what is the volume of each of the two parts of the cone if it is cut horizontally halfway up? (HINT: Find the volume of the whole cone, then the volume of the lower part. The latter is a frustum of a cone.)

Problem 16. What is the area of an ellipse with a long axis diameter of 5 feet and a short axis of 2 feet?

FORMULAS FROM PHYSICS

Many formulas of great importance in physics have the form of $XY = Z$ or $\frac{A}{B} = C$ and can be solved on the A, B and C scales.

For example, physicists define work, such as that required to lift a weight or move an object, as the product of the force times the distance through which the force acts, or

$$W = FD.$$

Another similar physical formula is that for the momentum of a moving object — the tendency of a moving object to keep moving. Momentum (in foot-pounds per second) is equal to the weight of the object in pounds times its velocity in feet per second or

$$\text{Momentum} = MV.$$

Still another comparable formula is Ohm's law. Ohm's law has to do with electricity and states that the amperage of a current flowing in a circuit is equal to the voltage (or pressure) divided by the resistance, or

$$I = \frac{E}{R}$$

where I is the current in amperes, E is the voltage and R is the resistance.

Here are some problems utilizing these formulas:

17. Work amounting to 35,000 foot-pounds was done in raising a statue weighing three-quarters of a ton to the top of a pedestal. How high is the pedestal?

18. A 3500-pound car is traveling along a highway at a speed of 55 miles an hour. What is its momentum in foot-pounds per second?

19. The wiring in an electric motor has resistance of 32 ohms, and is supplied with current at 115 volts. How many amperes of current will it draw?

COMMON ERRORS

In using powers and solving formulas similar to those described in the last two sections, be careful to avoid the following common types of mistakes:

$4^2 \cdot 4^2$ is *not* equal to 16^4 , but to 4^4 .

$8 - (-3)$ is *not* equal to 5, but to 11, because the two negatives cancel each other.

$x \cdot \frac{a}{b}$ is *not* equal to $\frac{ax}{bx}$ but to $\frac{ax}{b}$.

$\frac{a+b}{c}$ is *not* $\frac{a}{c} + b$, but $\frac{a}{c} + \frac{b}{c}$.

LOGARITHMS, POWERS AND ROOTS

In the course of working with your computer, you have made the acquaintance of powers of 10. By now, you can translate expressions like 10^5 into numbers in your head without any difficulty at all. But other numbers can be raised to powers, too, such as 14^7 , or 8^{11} , and it can take quite a while to multiply 14 by itself 7 times, or 8 by itself 11 times. However, there are scales on scale plate No. 1 that make it easy to compute powers.

The same scales can also be used to solve another kind of problem. Suppose, for instance, you multiplied 4 by itself 5 times (4^5). You would get 1024. Suppose now you asked what number raised to the 5th power would give 1024. Since we just worked it out, we know that number is 4, and we call 4 the 5th root of 1024. The scales used to calculate powers can also be used to find roots.

The scales for finding powers and roots are scale plate No. 1's inside scales D, E, and F. Notice that these scales are not equally spaced as are A, B, and C. They are *logarithmic* scales.

What Are Logarithms?

Logarithms are powers. All logarithms used with your analog computer are "base 10" logarithms, which means they are powers of the number 10. More exactly, the logarithm is the power to which 10 must be raised to equal that number.

This sounds somewhat like the powers of 10 you have been using to fit numbers to the A, B, and C scales. In fact, there is a close relation. We found $10^3 = 1,000$. Because 10 must be multiplied by itself 3 times to equal 1,000, the logarithm of 1,000 is 3. However, logarithms need not be whole numbers. Thus, $\log 4 = 0.602$ because $10^{0.602} = 4$.

Look at the list of numbers, powers and logarithms on Memory Board No. 1. You will find the logarithms or logs for many numbers, including the log of 10 itself ($\log 10 = 1$; why?) and of 4.

The same system is printed on scales D, E and F. Look at number 4 on scale D. Right next to it, on scale A, is .6, which is a close approximation of the log of 4 or 0.602.

Logarithms are handy because they convert computation of powers and roots to simple multiplications and divisions. For example, find 3^2 with logs. Look up $\log 3$ on your memory board. It is 0.477. Multiplying by 2, you obtain 0.954. A glance at the board shows that this is the log of 9.

With the computer's logarithmic scales, powers and roots can be figured as easily as multiplication products and division quotients on the A, B, and C scales.

To find powers with the computer, the basic procedure is to set the power on Scale A, and the number on Scale E. The log of the answer

will appear on Scale C of dial 2 when you have turned the dial to null.

Roots are also easily done. Take $\sqrt{4}$, the second or square root, of 4. This can be rewritten as $4^{1/2}$ (just as the third, or cube root, can be rewritten as the number to the power $1/3$, the fourth root as the number to the power $1/4$ and so forth.) $4^{1/2}$ can also be written as $4^{.5}$, or in log form, $.5 \log 4$.

Let us find $.5 \log 4$ on the computer. Set the power .5 on scale A of dial X and the number 4, on scale E of dial Y. Turn dial Z to null, and read the log of your answer on scale C. The log is .3 and the number corresponding to the logarithm is 2, which is, of course, the square root of 4. In this case, you did not have to convert your log because you could read the answer directly on scale F, but this is true only for logs smaller than 1.000.

When you deal with larger numbers, the interesting feature of logarithms is that the log of the answer tells you immediately the order of the magnitude of the number you are looking for.

To understand this, look again at your memory board. Notice that the numbers between 1 and 10 have logs between 0 and 1.000; numbers between 10 and 100 have logs between 1.000 and 2.000; numbers between 100 and 1,000 have logs between 2.000 and 3.000, and so forth. The digit that precedes the decimal point is called the log's characteristic, because it represents the order of magnitude of the number. The digits on the right of the decimal point are the mantissa. The mantissa gives the actual digits making up the number or antilog (as the number is also called) you are looking for. You remember, for instance, that $\log 2$ is approximately 0.3000. .3 is the mantissa, 0 is the characteristic. If you keep the same mantissa, and change the characteristic, you simply change orders of magnitude. Thus:

$$\begin{aligned}\log 2 &= 0.3 \\ \log 20 &= 1.3 \\ \log 200 &= 2.3 \\ \log 2,000 &= 3.3, \text{ etc.}\end{aligned}$$

You can now tackle powers and roots of any number. For instance, find 3^5 .

First, rewrite as: find Z where $5 \log 3 = \log z$.

The power 5 does not fit on scale A, so divide it by 10.

Now set the number 3 on scale E of dial Y. Turn dial Z to null, and read the log of the answer on scale C. It is approximately 0.23. But, you had divided the power by 10, so now multiply the log of the answer by 10. It becomes 2.3. 2 is the characteristic number, and .3 is the mantissa. Already you know that the answer is between 100 and 1,000. Read on scale F the antilog of .3, which is 2. So your final answer is approximately 200. It is easy to remember that the answer will always be in three figures if the characteristic is 2, or in four figures if the characteristic is 3, etc.

Take another example: $2,500^5$. Here, neither the number nor the power fit on the scales. You can see that the answer will be a staggering number, and without the computer it would take quite a while to figure out.

Again, set the power, .5, on scale A. Note that you divided it by 10.

Set the number on E, after dividing it by 1,000 to make it fit the scale. It becomes 2.5—make sure you note that you have divided it by 10^3 .

Read the log of the answer on scale C. It is approximately 0.2. Multiply it by 10, since you had divided the power by 10. It becomes 2.000. The mantissa is zero, which translates on scale F, to the digit 1. The characteristic is 2 — so the number becomes 100.

But remember that you had divided the original number by 10^3 . Now you have to multiply the answer — but by $(10^3)^5$, because 10^3 must also be raised to the fifth power. It becomes 10^{15} .

So your final answer is approximately 100×10^{15} which is 10^{17} or 100,000,000,000,000,000.

You will notice that the logarithmic scales are not numbered from zero, like the linear scales, but start at 1. In other words, 1 on the log corresponds to 0 on the linear scales. This is because the log of 1 is zero. So 1 on the log scale must be put in a position corresponding to 0 on the linear scale. Zero itself has no log and can have no place on the log scale, because zero can be raised to any power — can be multiplied by itself as many times as you please — and it's still zero.

Now, we have one thing left out. What about the log of numbers between 0 and 1.0? These have *negative* logs, just as very small numbers have negative exponents when writ-

ten in power form. We will take up negative logs later.

More on Roots.

You have already solved one root problem. A moment ago, you found the square root of 4 by rewriting it as $4^{.5}$ and solving as a power. Any root up to about the tenth can be found simply and fairly accurately by the same method — and it isn't often that you need go beyond the tenth root of a number.

Thus, the square root can be found by setting the dial on scale A to $\frac{1}{2}$, or .5. For cube root, set A at .333; the fourth root at .25; the fifth at .20, and so forth. Then set the number whose root you seek on scale E of dial Y.

Let us find the cube root of 500. Set .33 on scale A. To set 500 on scale E, proceed as you did in finding powers of large numbers. Divide 500 by 100 and set 5 on scale E. Adjust dial to null and read the log of the cube root of 5 on scale C. It is .233.

Now remember you divided 500 by 100. So, to find the final answer, you must multiply the cube root of 5 by the cube root of 100. Actually, you do not have to figure out the cube root of 100 — simply take the logarithm of 100, which is 2, and divide it by 3 to find the logarithm of the cube root of 100. It is .667. Add this to the log of the cube root of 5.

$$.233 + .667 = .900$$

.900 is the logarithm of the cube root of 500. Because the characteristic is 0, you can already see that the answer will be between 1 and 10. Set the hairline on .900 on dial Z, scale C, and read the answer on scale F. The cube root of 500 is approximately 8.

PROBLEMS

20. Find 7^7 .
21. Find the cube root of 15,000.
22. Find the radius of the earth. The earth's circumference is 40,000 kilometers. Use the memory board conversion table for an answer in miles.
23. What is the volume of the earth?
24. There are about 5 million cubic miles of ice on the land surfaces of earth. If all this ice melted and ran into the oceans — which cover $\frac{7}{10}$ of the total surface of the earth —

by how much would the level of the oceans rise? Ice has 1.1 times the volume of an equivalent weight of water.

25. Find $6.5^{3.4}$.

26. What is the square root of the cube of 300?

27. And what is the cube of the square root of 450?

COMPOUND INTEREST AND GROWTH

Many banks pay *compound* interest on savings accounts. What does this mean? Simply that if a sum of money, say \$100, is left on deposit for more than one interest period, the interest is added to the sum on which interest is figured. Suppose the bank pays 2% interest "compounded" every six months. At the end of the first six months, the \$2 interest is added to the \$100, and the sum on deposit becomes \$102. At the end of the second six months, the interest is figured on \$102, then *that* interest is added to the principal, and so on.

Figuring how much a sum of money in a compound interest account will grow to over a period of years can be quite tedious. But it's easy to arrive at an approximate figure with your computer.

The formula for compound interest is:

$$A = P(1 + i)^n$$

where A is the final amount, P is the sum you started with, i is the interest rate for each period on which interest is paid, and n is the number of interest periods.

To solve, first find $(1 + i)^n$. Convert this to logarithmic form:

$$\log [(1 + i)^n] = n \log (1 + i)$$

Change i, the interest rate to decimal form. Thus, 2% = .02, and $1 + i = 1.02$.

Now set n on scale A, remembering to divide by 10 to fit n on the A scale. Set $(1 + i)$ on scale E. Turn dial Z to null and read on scale F. Reset this value on scale A, and set P on scale B. Read the final answer on scale C.

The compound interest formula can also be used for *growth* problems. These include such problems as how large a country's population will be after n years if it increases at a rate of so-and-so-many per cent a year; or

what output an industry will have if it grows at a certain rate per year. Growth problems are solved exactly as compound interest problems.

PROBLEMS

28. How much will \$110 amount to if left on deposit for nine years in a 4% compound interest account compounded semiannually (paying 2% each half year)?

29. If you put \$50 in a compound interest account paying 1% quarterly, how long will it take you to double your money?

30. The world's population passed the 3 billion mark in 1961, and is growing at a rate of 1.7% a year. In what year will the world population reach 4 billion if it continues growing at the present rate?

RADIOACTIVE DECAY

When radioactive substances like radium or any of the isotopes made at Oak Ridge for use in science and industry give off radioactivity, they also change into something else. Radium, for example, changes into a gas called radon (which is itself radioactive and which likewise changes into something else when it gives off radiation).

The process of giving off radiation and changing into another substance is called *radioactive decay*. A remarkable feature of the process is that it takes place at a constant rate. Thus, if you have an ounce of a material that decays at a rate of 5% a day, at the end of the first day, 95% will be left. During the second day, 5% of *that* will decay, leaving 95% of 95%, or $.95 \times .95$ of the original ounce of material, and so forth.

All of this should have a familiar ring. For it is the compound interest problem, with something decreasing instead of growing. In fact, the formula for solving it is nearly the same:

$$A = I(1 - d)^t$$

where A is the amount of radioactive material left after t time periods; I is the initial amount of radioactive material and d is the radioactive decay constant (the percentage of material decaying in time period t).

Although the radioactive decay and compound interest formulas are look-alikes, how-

ever, that minus sign in $(1 - d)$ introduces a complication. We are going to have to use negative logs.

Let us take a specific example.

A laboratory has 2 ounces of a radioactive material that decays at a rate of 10 per cent every 30 days. How much will be left at the end of three 30-day periods, or 90 days?

$$A = 2(1 - .1)^3$$

$$= 2(.9)^3$$

First, find $(.9)^3 = 3 \log .9$

If you look up the log of 90, you will find that it is 1.954, and of 9, that it is 0.954. However, we must find the log of .9. To get that, we simply need to go down one more number on the scale for the characteristic (the number to the left of the decimal point). In logs, though, this is done in a special way. For log .9, we write: $9.954 - 10$. (If we wanted log .09, we would write $8.954 - 10$, and so on.)

$$\text{So } 3 \log .9 = 3(9.954 - 10)$$

$$= 29.862 - 30$$

Now, to convert back to $(.9)^3$, subtract 20 from both parts of the log. This leaves $9.862 - 10$. Set .862 on scale C. Read 7.2 on scale F. But the characteristic 9. - 10 tells you the answer must be .72.

Reset this on scale A. Set 2 (remembering to divide by 10) on scale B. Read the answer (remembering to multiply by 10) on scale C. At the end of 90 days, 1.44 ounces of the radioactive material will be left.

PROBLEMS

31. A radioactive isotope of the element cobalt emits rays useful in treating cancer, and many hospitals now have radioactive cobalt bombs. One isotope of radiocobalt has a half-life of 5.2 years. That is, half of the original amount will be gone in 5.2 years. How much of 10 grams of radiocobalt in a bomb purchased by a hospital on January 1, 1955 will still be left on January 1, 1970?

32. Carbon-14, a radioactive form of the element carbon, occurs in small amounts in plants and animals. It has a half-life of 5,720 years. Scientists take advantage of this to date fossils, by comparing the amount of carbon-14 left in a fossil with a comparable new sample. If only one-eighths of the original carbon-14 is left in a fossil, how old is it?

TRIGONOMETRIC FUNCTIONS

Trigonometry deals with the relationship between the sides and angles of a triangle. With the help of trigonometry, you can deduce all of the dimensions of a triangle if you know the values of two of its angles and a side, two sides and an angle, or all three sides.

Trigonometry is an indispensable tool for many problems, especially in navigation, engineering and ballistics, the science that deals with the motion of projectiles.

Trigonometric functions are best visualized by relating them to a circle. In Fig. No. 31, values of various trigonometric functions are expressed in terms of the circle's radius, which is counted as 1. Three circles are shown to indicate how the functions vary with the size of angle.

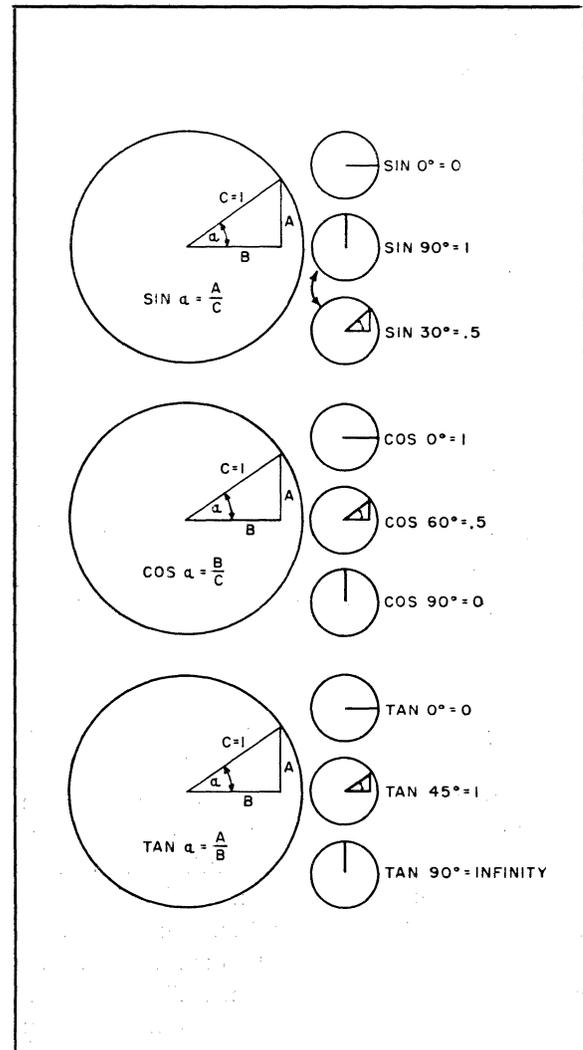


FIG. NO. 31

The same trigonometric relations can also be expressed in terms of geometry on a right-angle triangle, where they follow the theorem of Pythagoras. These relationships are described on your memory board.

On your computer, values of the sine (sin) and cosine (cos) of angles up to 90 degrees, can be read directly on any dial of Scale Plate No. 2. To find the sine of an angle of 20°, for example, set the pointer to 20 on scale D, E or F of Scale Plate No. 2, and read the answer directly on scales A, B or C.

$$\sin 20^\circ = .342$$

Note that while the sine increases as the angle increases, the cosine decreases. Both sine and cosine can thus be represented by curves of the same shape, but out of step ("out of phase," mathematicians and engineers say) with each other, as in Fig. No. 32. On your computer, both the sine and cosine can be read on the same dial, but the angle

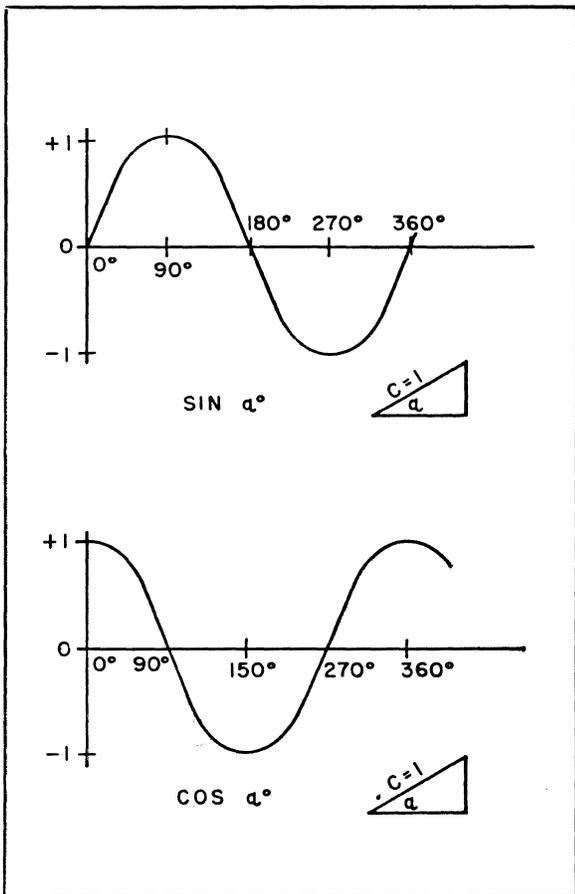


FIG. NO. 32

should be set on the appropriate trigonometric scale.

For problems using sine and cosine functions, as $.3 \sin 37^\circ$, set the multiplier (.3) on scale A, the angle (37°) on the sin scale of dial Y, and adjust dial Z for null. The answer can be read on scale C:

$$.3 \sin 37^\circ = .18$$

If the multiplier does not fit on the scale, use powers and reconvert the answer as you do in multiplication or division.

Sometimes you may find that the angle in a problem is larger than 90° . A table on your memory board indicates the values of the sine and cosine for angles up to 360° , the complete circle. But in most practical problems, the angles you deal with are *acute* angles, that is, angles of less than 90° .

Sometimes a problem may involve a tangent, cotangent, secant or cosecant of an angle. To avoid burdening the dials, these are not indicated, but can be found by using trigonometric relationships on the memory board.

To find cosec 30° , use the relationship

$$\text{cosec} = \frac{1}{\sin}$$

In this case, the answer will be

$$\text{cosec } 30^\circ = \frac{1}{.5} = 2$$

The memory board designed for use with Scale Plate No. 2 gives some of the most useful formulas using trigonometric functions.

Let's say you want to calculate the range of a gun. You know the velocity of the bullet as it leaves the barrel and the angle at which the barrel is pointed. Neglect air friction.

Say the muzzle velocity is 3,000 feet per second, and the angle of elevation of the barrel, 30° .

The formula for the range is:

$$R = \frac{V_0^2 \cdot \sin 2A}{32}$$

where A is the elevation in degrees, R the range in feet, and V_0 the muzzle velocity in feet per second.

With a muzzle velocity of 3,000 feet per second and an angle of 30° , the formula becomes

$$R = \frac{(3,000)^2 \cdot (.866)}{32} = \frac{9,000,000 \cdot (.866)}{32} = \frac{7,794,000}{32}$$

The range is 240,000 feet.

PROBLEMS

33. Find $\sin 23^\circ$.
34. Find $\cos 40^\circ$.
35. Find $\tan 170^\circ$.
36. Find $\operatorname{cosec} 45^\circ$.
37. What is the angle at which a cannon with muzzle velocity of 2,000 feet per second must be pointed to have a horizontal range of 25,000 feet?
38. How far ahead of a target must a plane, flying at 700 miles per hour and at an altitude of 20,000 feet, drop a bomb to strike the target?
39. You are half a mile away from a building 300 feet tall. At what angle from the horizontal will you see the building's top?

RECIPROCAL SCALES

Scale Plate No. 3 has been especially designed to enable you to perform multiple operations without resetting your dials. Thus you can solve a great variety of problems more rapidly.

Take, for instance,

$$\frac{.3 \times .8 \times .5}{.6} = ?$$

Set dial X to .3 on scale A on Scale Plate No. 3 and dial Y to .8 on scale B. Then adjust dial Z for null. It will be approximately at .24. Now, to divide by .6, reset dial Y to .6 on scale B, and adjust dial X to null. It should show .4. Now again reset dial Y to .5, the last multiplier, and adjust dial Z for null. The final answer on scale C is .2.

This could actually be done on Scale Plate No. 1 (try it), but certain formulas that cannot be solved directly on other scales can be worked out with the use of the reciprocal scale, E, on the third scale plate.

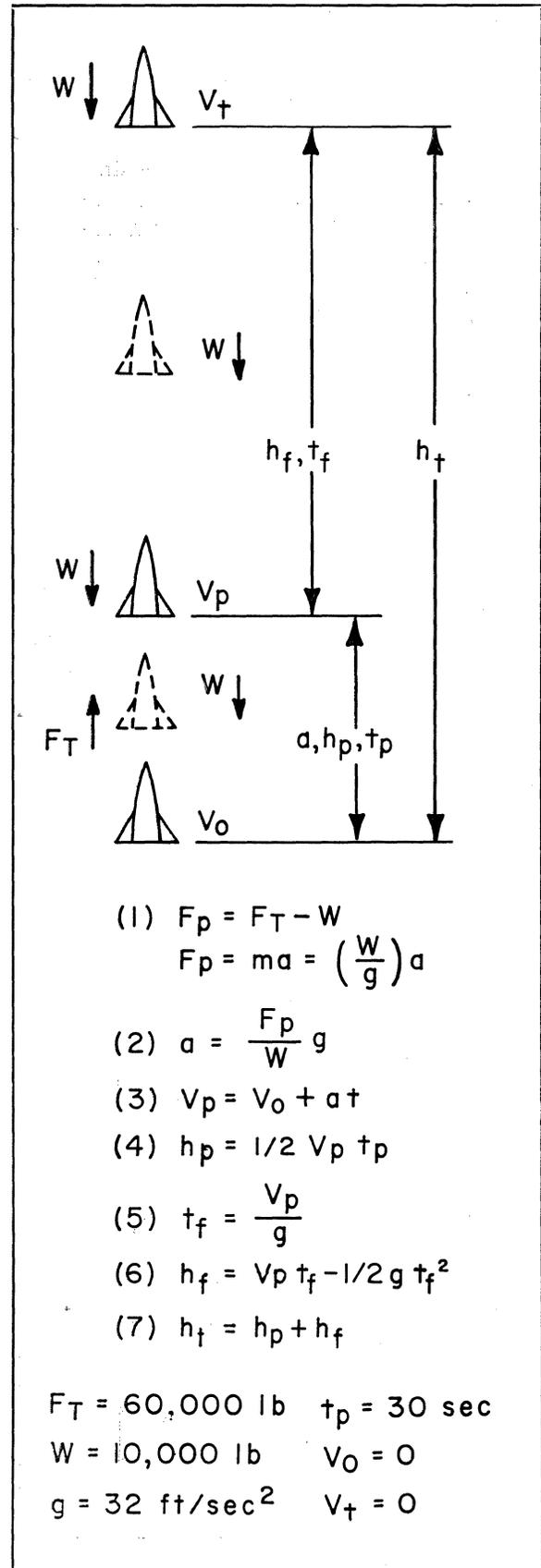


FIG. NO. 33

These scales, you will notice, simply go backwards. They have been scaled so that multiplication can be performed instead of division, and vice versa.

Using scales A, B, C and E, you can directly find the answer to $.4 \times .7 \times .3$, by setting dial X to .4 on scale A, dial Y to .7 on scale B, adjusting dial Z for null, resetting dial Y to .3 on scale E and readjusting dial X for null. The answer is read on scale A.

Scale D is also a special scale. It is useful in solving problems containing a squared term, such as the formula for the area of a circle. Set the radius of the circle on scale D (pot X automatically squares the radius, which can be read on scale A), set π on scale B and read the area on scale C. If you have to divide the radius by 10, for example, don't forget to carry 10^2 as a multiplier.

Here is a fairly complicated ballistic problem that can be solved quite easily on Scale Plate No. 3.

As shown in *Fig. No. 33*, a ballistic missile has a weight W of 10,000 lbs. and a thrust power F_p of 60,000 lbs. The burnout time is 30 seconds. If this missile is shot straight up, how high will it go?

The effective thrust is the thrust of the engine minus the weight of the missile, or:

$$F_p = 60,000 - 10,000 = 50,000 \text{ lbs.}$$

The acceleration during the powered part of the flight is equal to the effective thrust, divided by the weight of the vehicle, multiplied by g , the acceleration given to a falling body by the earth's gravitational pull. At the earth's surface, g is approximately 32 feet per second per second; in other words, at the end of each second, a falling body will be traveling 32 feet per second faster than at the end of the previous second.

Thus the acceleration during powered flight is:

$$A = \frac{F_p}{W} = \frac{50,000}{10,000} \cdot (32)$$

Using scales A and B, this can be found to be 160 feet per second every second, or 160 feet/sec².

The velocity of the missile at the end of the 30 seconds before burnout can be found by

setting 30 seconds (rather, $.3 \times 10^2$ seconds) on the reverse scale E:

$$V_p = a \cdot t$$

$$V_p = 160 \cdot 30 = 4,800 \text{ feet per second.}$$

The height reached by the end of the powered flight, H_p , is half of the final velocity multiplied by the time of the powered flight. Therefore, reset half of the velocity, 2,400, on scale A, (you have to divide it by 10^4 to fit the scale). Multiply it by burnout time, 30, to be set on dial B. The altitude reached during the powered flight of the missile is read on scale

How much longer will the missile coast up? It will now be slowed down by the pull of gravity, 32 feet per second per second.

Set 32 (or 3.2) on scale B, adjust dial X to null, reading the answer on scale A. The time of free flight will be 150 seconds.

To find out how much higher the missile will go after the end of powered flight, multiply its initial non-powered velocity by the time of flight, and subtract the distance "lost" through the effect of gravity:

$$H = Vt - \frac{1}{2}gt^2$$

The time of free flight, t , is already on scale A. Set the velocity after powered flight, 4,800 on scale B, and adjust dial Z to null. Note the answer. This is how far the missile would go in 150 seconds if it were not pulled back by gravity.

Now to figure out how far the missile will go against gravity, subtract the distance "lost" through the deceleration of gravity during that time. The distance "lost" is:

$$\frac{1}{2} \cdot 32 \cdot (150)^2$$

Subtract this from the distance the missile would reach in 150 seconds without decelerating.

The answer is $720,000 - 337,500 = 382,500$ feet.

The maximum altitude reached by the missile would be the altitude of powered flight, plus the altitude it would coast to after powered flight.

$$72,000 + 382,500 = 454,500 \text{ feet.}$$

Then it would fall back.

This is lengthy, but actually not too complicated. For further reference, here are the formulas permitting you to calculate altitudes

and times of flight of powered and ballistic missiles:

The effective power thrust, F_p , equals the engine's thrust, F_t , minus the weight, W , of the vehicle.

$$F_p = F_t - W$$

F_p is also equal to the mass multiplied by the acceleration given by the engine, and also equals the weight of the vehicle, divided by earth's gravitational pull, and the result multiplied by its acceleration during powered flight:

$$F_p = ma = \frac{w}{g} \cdot a$$

$$\text{The acceleration, } a = \frac{F_p \cdot g}{W}$$

The velocity of the vehicle at the end of powered flight is equal to its initial velocity (usually zero) plus the product of time of flight by acceleration:

$$V_p = V_0 + At$$

The altitude after powered flight is half the final velocity multiplied by the time of powered flight:

$$H_p = \frac{1}{2}V_p \cdot t_p$$

Coasting time is the final powered velocity divided by the earth's gravitational pull:

$$t_g = \frac{V_p}{g}$$

And the maximum altitude to which it will coast is the maximum powered velocity multiplied by coasting time, minus half of the product of earth's gravitational pull by the square of coasting time:

$$H_f = V_p t_f = \frac{1}{2} g t_f^2$$

The final altitude is the sum of the altitude reached after powered flight and the coasting altitude.

$$H_p + H_f$$

By using these formulas, you can now figure out what it takes to send a satellite toward the moon, and what it takes to rocket it out of the solar system.

PROBLEMS

40. A rocket weighing 20,000 pounds and having a thrust of 40,000 pounds is fired straight up. Its engine burns for 1 minute. How high will the rocket climb?

41. If the missile in problem 40 were to eject a capsule weighing 1000 pounds at burnout, how high would the capsule go?

And here is a final problem:

42. The velocity of escape from the earth is about 7 m/sec., and 37 mi/sec on Jupiter. The weight of an object on a planet is directly proportional to the velocity of escape from that planet. If a man on earth weighs 180 pounds, what would he weigh on Jupiter?

ADDITIONAL PROBLEMS

Here is a selection of additional problems to work out on your computer:

43. The sun has a diameter of 864,000 miles, the earth, about 8,000 miles. How much bigger in volume is the sun than the earth?

44. The world's tallest structure is a television tower station in Cape Girardeau, Md.: 1,676 feet. Assuming it is on a flat surface and that the sun is at an angle of 25 degrees above the horizon, how long a shadow would the tower cast?

45. In 1960, the U. S. Navy bathyscaphe Trieste made a dive of about 35,000 feet in the South Pacific. Knowing that a liter of water weighs one kilogram, find out what was the pressure per square inch at the surface of the manned cabin of the bathyscaphe.

46. The spherical cabin was about 6½ feet in diameter. What was the total pressure exerted on it at that depth?

47. Explorer I, the first satellite launched by the U. S. in January 1958, had an initial perigee of 403 miles, and an apogee of 2,450 miles. What is the distance traveled by the satellite during a single orbit around the earth? (Earth's radius is 4,000 miles.) The perimeter of an ellipse is approximately given by:

$$P = \pi (a + b)$$

where a is half of one axis, and b is half the other.

48. Sputnik I, the first satellite launched by the Soviets in October 1957, had a perigee of

140 miles, an apogee of 560 miles. It traveled around the earth in about 90 minutes. What was its average speed?

49. On May 5, 1961, Commander Alan B. Shepard, Jr., became the first American to pierce the space barrier. At lift-off, the weight of the complete Redstone Mercury was 66,000 pounds. The missile had a thrust of 78,000 pounds, and would deliver power for 2.5 minutes, consuming 50,000 pounds of fuel. See Fig. No. 34.

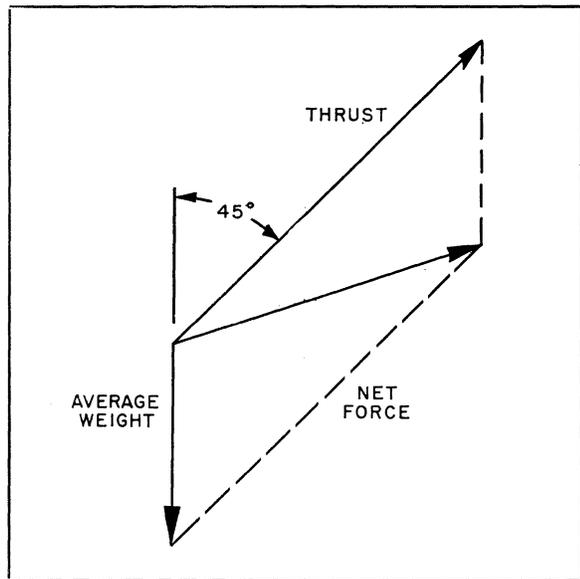


FIG. NO. 34

- Calculate the average weight of the rocket for the first 2.5 minutes.
- Since the rocket follows a parabolic trajectory, the average weight of the rocket and the thrust oppose each other only part of the flight. The relation between the average weight of the rocket, the thrust, and the net force along the flight path for the first 2.5 minutes is given by the diagram below. Calculate the average acceleration in feet per second per second along the flight path, knowing that $a =$

$$a = F \cdot \frac{g}{W}$$

- What is the speed of the capsule in miles per hour at the point of separation, 2.5 minutes after lift-off? (See if you can find the right formula in the sample ballistic problem on Page 35.)

- The capsule at separation is at an altitude of 264,000 feet and a trajectory of + 45 degrees. What will be its altitude at apogee?

Use

$$H = \frac{V_0^2 \cdot \sin^2 A}{64}$$

- What is the total flight time to apogee? You may find the formula $S = \frac{1}{2} g t^2$ useful here.
- The average velocity of the capsule from lift-off to apogee is 38 miles per minute at an angle of + 37.2 degrees. Calculate the range and altitude of the capsule at apogee.
- The capsule now begins to lose altitude. How long will it take from apogee to reach 10,000 feet, where the main capsule parachute will open? Assume that air friction adds an extra 162 percent to the capsule's flight time in the portion of the descent after it is back down to an altitude of 50 miles? Use

$$S = V_0 t - \frac{1}{2} g t^2$$

- At apogee, Commander Shepard fires the retro-rockets to decrease the one-ton capsule's horizontal velocity. The rockets burn for 60 seconds, producing a thrust of 416 pounds. When the capsule re-enters the atmosphere at an altitude of 50 miles, air friction causes a horizontal deceleration of 13.1 feet per second per second. Calculate the range of the capsule when the main chute opens.
- As the capsule reentered the atmosphere, its velocity at one time was decreasing by 218 miles per hour per second. If Commander Shepard's normal weight was 160 pounds, what was his weight at this time?

$$F = \frac{w}{g} a$$

- After the large parachute opens, the capsule descends at 30 feet per second. What is the total flight time between lift-off and landing?
- The one-ton capsule has a volume of about 60 cubic feet. It takes in sea water (62.4 pounds per cubic foot) at a rate of 10.5 gallons per minute. How long will the capsule float?

ANSWERS TO PROBLEMS

1. 1,771
2. 227,322
3. 35.8
4. 198
5. 1,540
6. 24.9×10^{-12}
7. $.746 \times 10^{-2}$
8. 1.52×10^{-4}
9. 25.4×10^{12} miles
10. Area of Central Park = 1.29 square miles
11. 85.9×10^6 cubic feet
12. 104.5×10^6 cubic feet
13. 34.9×10^6 ; 1.16 per cent
14. 12.57 cubic feet
15. 1.77 cubic feet; 12.4 cubic feet
16. 7.85 square feet
17. 23.4 feet
18. 2.82×10^5 foot pounds per second
19. 3.6 amperes
20. $.81 \times 10^6$
21. 24.6
22. 3,960 miles
23. 2.6×10^{11} cubic miles
24. 174 feet
25. 580
26. 5,200
27. 9,500
28. \$158.00
29. 17.5 years
30. 1990
31. 1.34 grams
32. 17,160 years
33. .391
34. .766
35. - .176
36. 1.41
37. 5.8 degrees
38. 36,200 feet
39. 6.5 degrees
40. 115,200 feet
41. 115,200 feet
42. 952 pounds
43. 1.26×10^6
44. 3,600 feet
45. 15,100 pounds per square inch.
46. 144,000 tons
47. 34,100 miles
48. 18,200 miles per hour
49.
 - (a) 41,000 pounds
 - (b) 44 feet per second per second
 - (c) 4,500 miles per hour
 - (d) 115 miles
 - (e) 5 minutes
 - (f) Range: 151 miles; altitude 115 miles
 - (g) 4.5 minutes
 - (h) 302 miles
 - (i) 1,600 pounds
 - (j) 15 minutes
 - (k) 20 minutes

ADDENDUM

In solving division problems, such as Problem #4 on Page 26, you will note that it is necessary to adjust the numbers so that you will have Dial C turned further to the left than Dial B. This means that in order to obtain a null on Dial A, you must set the pointer on Scale C to .095 (located between 0 and .1). Then, set the pointer on Scale B to .48. Now, rotate the dial on Scale A until you get a null at the answer, which should be at .198. Of course, you must readjust the decimal point in the answer to get 198. In other words, in all division problems, if you are unable to tune to a null on Scale A, then, readjust the setting on Scale C so that it is turned further to the left than Scale B.

ACCURACY: You may increase the degree of accuracy of your computer by making the following adjustments:

1. Loosen the retaining nuts on dial potentiometers X, Y, and Z.
2. Next, rotate the three dials to the extreme counter-clockwise position which will put the hairline on, or below, the zero point on the scale. Keeping the dials in this position, re-tighten the retaining nuts, making sure the locating tabs on the potentiometer are in their holes.

GENERAL ELECTRIC

REPLACEMENT PARTS PROCEDURE

HOW TO OBTAIN SERVICE:

DEFECTIVE MATERIAL AT TIME OF PURCHASE: Within ninety (90) days from the date of purchase, the Company will replace parts which are defective in material or workmanship. To obtain this service simply fill in the **WARRANTY COUPON** on the bottom of this page and mail it along with the defective part to

GENERAL ELECTRIC COMPANY
 EDUCATIONAL SCIENCE KIT SECTION
 PRODUCT SERVICE
 1001 BROAD STREET
 UTICA, NEW YORK

Please note that the warranty does not cover damage caused by the user.

SERVICE FOR ASSEMBLED KIT: Within ninety (90) days from the date of purchase, if the finished, assembled kit does not operate, it may be returned to the factory for service. Before doing this, however, you may wish to consult with a science teacher or other qualified person. If this is not possible, pack the equipment carefully in a sturdy carton and ship the kit **PRE-PAID** via **RAILWAY EXPRESS** to the address given **ABOVE**. Be sure to include the **WARRANTY COUPON** from the bottom of this page along with a two dollar (\$2.00) check or money order made payable to the **GENERAL ELECTRIC COMPANY** to cover handling costs. Please note that the warranty does not cover damage caused by the user.

ORDERING REPLACEMENT PARTS: At any time, should you desire an additional part, for any reason, you may obtain it by filling out and mailing the **PARTS ORDER FORM** on the bottom of this page. On orders of one dollar (\$1.00) or more, please enclose check or money order in the exact amount, payable to the **GENERAL ELECTRIC COMPANY**. On orders for less than one dollar (\$1.00), coins will be accepted. Mail your parts order to: **GENERAL ELECTRIC COMPANY, P.O. BOX #831, UTICA, NEW YORK**

REPLACEMENT PARTS LIST

CATALOG NUMBER:	DESCRIPTION	UNIT PRICE	CATALOG NUMBER:	DESCRIPTION	UNIT PRICE	CATALOG NUMBER:	DESCRIPTION	UNIT PRICE
EK-104	KNOB, TONE & CALIBRATE	\$.25	→ EK-156	22K Res., 1/2 Watt (R4)	.25	EK-240	CHASSIS MTG. BRKT.	.25
EK-111	POSITIVE BATTERY CONTACT	.25	→ EK-158	33 ohm Res., 1/2 Watt (R7,8)	.25	EK-242	HEX-NUT (Pkg. 5)	.25
EK-112	NEGATIVE BATTERY CONTACT	.25	→ EK-175	1.5K Res., 1/2 Watt (R1,5)	.25	EK-243	3/8" U CLIP (Pkg. 5)	.25
EK-113	SPRING CONNECTOR		EK-216	CABINET TOP	1.50	EK-244	PLATE #1 LOG SCALE	
	ASSEMBLY (5)	.25	EK-217	CABINET BOTTOM	2.25		w/MEMORY BOARD	.75
EK-115	SPRING, FOR SWITCH (5)	.25	EK-218	CABINET CLIP	.25	EK-245	PLATE #2 SIN COS SCALE	
EK-116	SCREWDRIVER	.25	EK-220	EARPHONE HEADBAND	.50		w/MEMORY BOARD FOR	
EK-117	EARPHONE	2.50	EK-233	KNOB, DIAL	.50		PLATE #1	.75
EK-121	SCREW, SHEET METAL (7)	.25	EK-234	CIRCUIT BOARD	.50	EK-246	PLATE #3 SQUARE-RECIPROCAL	
EK-122	FASTENER, SPEED NUT (5)	.25	EK-235	VERTICAL CONTROL PANEL	1.00		SCALE w/MEMORY BOARD	
EK-129	HOOKUP WIRE (3 feet)	.25	EK-236	HORIZONTAL CONTROL PANEL	1.00		FOR PLATE #2	.75
EK-134	10K Res., 1/2 Watt (R3)	.25	EK-237	CENTER BRKT. CONTROL		→ EK-248	200K VARIABLE RES., (R2)	.75
EK-135	SPDT SLIDE SWITCH (SW1)	.50		PANELS TO CABINET BOTTOM	.25	→ EK-249	200 ohm VARIABLE RES., (R9)	.75
EK-136	TRANSISTOR (TR1,2,3)	1.75	EK-238	SPACER BRKT. CIRCUIT BOARD		→ EK-250	300 ohm VARIABLE RES.,	
EK-140	BATTERY HOLDER	.25		TO VERTICAL PANEL	.25		(R10, 12)	1.25
EK-147	CONNECTOR TOOL	.25	EK-239	SUPPORT BRKT. CONTROL		→ EK-251	10K VARIABLE RESISTOR	
EK-149	.05mfd., CAP., (C1,2)	.25		PANELS TO CABINET	.25		(R11)	1.25

The above prices include the standard fee for handling costs.

 Please PRINT IN INK because these forms will be used to fill your order and will become the label for returning parts to you.

WARRANTY COUPON EF-140

THIS COUPON NOT VALID AFTER 90 DAYS FROM THE DATE OF PURCHASE.

Date kit was purchased

Where purchased (Dealer)

..... (Address)

Please send me replacements for the following defective parts:

CATALOG NO.	DESCRIPTION
-------------	-------------

I am sending my Analog Computer and \$2.00 for service at the factory.

PLEASE MAIL TO:

NAME

ADDRESS

CITY STATE