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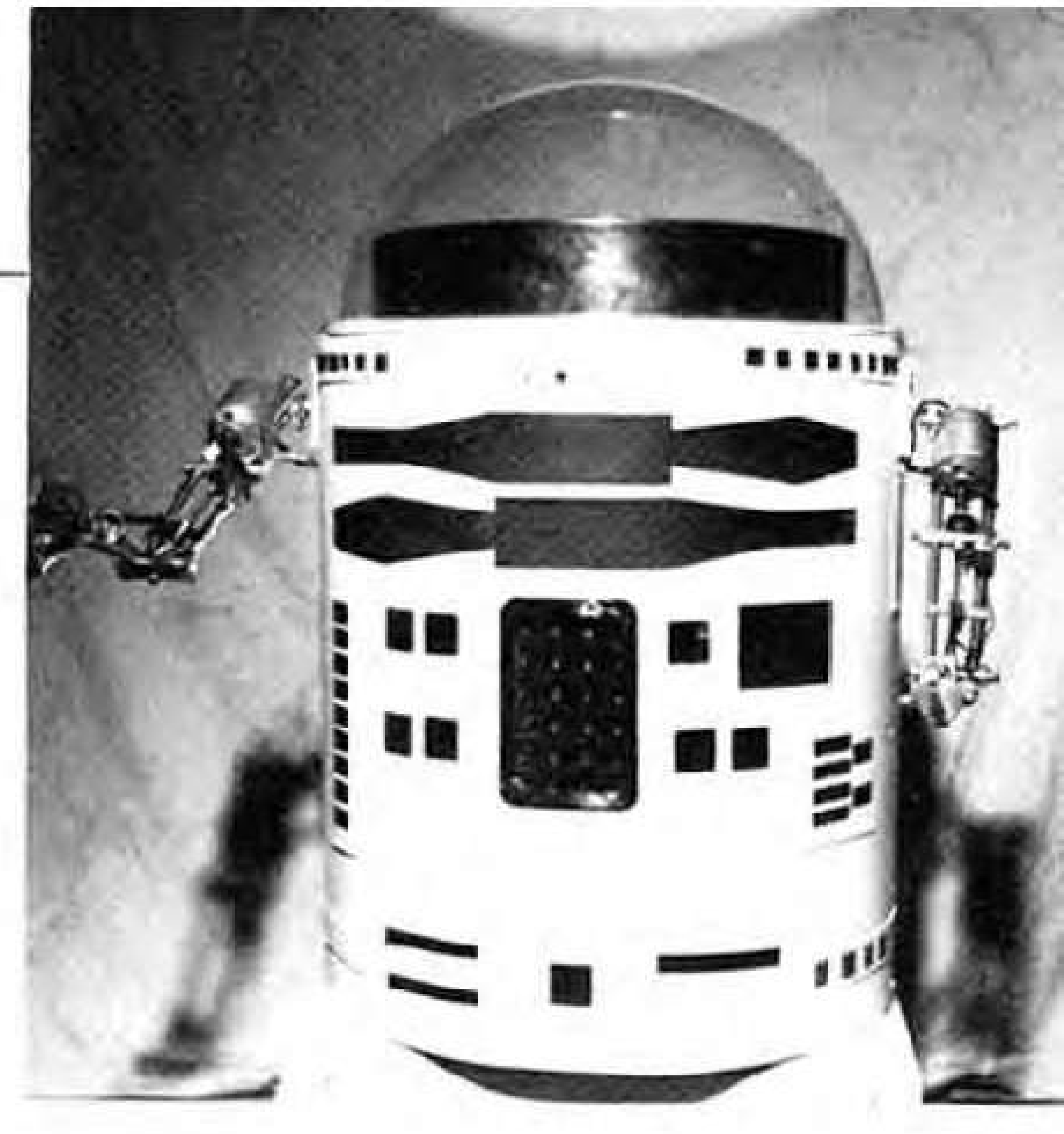
UNICORN-1 ROBOT



Ready for your own robot? You can construct one by following this multi-part series—and you won't need an engineering degree or special equipment, either.

JAMES A GUPTON, JR.

ROBOTS ARE BECOMING VERY HOT ITEMS. They have already made a name for themselves as movie and TV stars, chess players, artists, typists, advertising men, and assembly-line workers in Detroit. This past April, a three-day conference and an exposition on robotics was held in New York.

This series of articles detailing the construction of a robot called Unicorn-One (a name loosely derived from *Uni*versal *Con*trollable *R*obot) may not tell you how to build a device as elegant or articulate as *C3-PO*, but it will explain, step-by-step, how to design and assemble a robot that will be fully mobile, with manipulator arms to grasp, lift, and carry. Those features, in combination, will enable your robot to perform a wide variety of useful functions.

Unicorn-One is *truly* universal. The same robot body you will build can be operated from a control panel linked to it by cable, by remote radio control, or even by computer. It will even be possible to add an on-board computer to give the robot the ability to "think" for itself. As you will see, Unicorn-One's expansion capabilities are really limited only by what you want it to do.

The first parts of the series will deal with the construction of the mechanical portion of the robot—the object being to build a working mechanism for a reasonable amount of money.

You'll be shown how just a few common tools can be used to work steel and aluminum to almost machine-shop perfection. With a little ingenuity, an operational version of Unicorn-One can be built for about $200. Even if you purchase everything off-the-shelf, the cost should not exceed $400.

Easy-to-follow instructions will be provided to assist you in the assembly of the robot's manipulators (arms), end-effectors (hands), body, and mobility base, and will detail all wiring necessary to power its moving parts. For convenience, this wiring will be brought out to a terminal strip, where it can be connected to whatever type of control equipment you desire to use.

Later installments will describe how the robot can be controlled in any of several different ways—from a cable-connected console or by radio link, providing for both manual and computer-controlled operation.

Provision is also made for the installation of an on-board computer which can be programmed in advance, reprogrammed in mid-sequence, or even left to operate on its own.

The final portion will discuss ways of providing Unicorn-One with senses such as touch and sight, giving it a way to understand and communicate with people, and, in addition, giving it the ability to react to its environment without human intervention.

Basic mechanical components

Since we are building a robot from scratch, it might be a good idea to become familiar with some of the major components which affect its operation.

There are two electro-mechanical parts which are used to impart motion to the robot—motors and solenoids.

Motors are used for continuous motion (in the mobility base, for example, to get from one place to another, or in the arms, for lifting). Solenoids are usually used for a "one-shot" effort—say, opening or closing a grasping member.

Several different types of motors are used in Unicorn-One. Typically, they are low-voltage, high-speed, DC motors which are slowed down (they operate at several thousand RPM) to do what we want them to. That slowing-down is accomplished by gears, which gives us two benefits.

First, the rate of speed is reduced to a "real-world" level and, second, each time the speed is reduced by half, the torque (effective power) is doubled. That allows us to use inexpensive motors to give our robot a reasonable amount of strength. The same principle is used in automobile transmissions. (You can spin your wheels in low gear, but you can't start to build up any real speed until you get into second or higher.)

To put it in mechanical terms, if a motor spins at 6000 RPM, it won't do much for our robot arm unless it is geared down to make the action slower and more powerful. If we attach a 12-tooth gear to the motor, and mesh that with a 24-tooth gear, we'll achieve a speed reduction of 1:2 (12:24) and, at the same time, double the effective power of the motor. Every time the twelve-tooth gear turns once, the other will make only half a revolution, while transmitting the full power of the entire original revolution—which, if you add it up, doubles the original power of the motor.

GLOSSARY

Anti-backlash gear—Gear used to reduce or eliminate backlash. See BACKLASH, GEAR.

Angular motion—Rotary motion about an axis, as in the case of wheels or gears.

Backlash—Unwanted "rebound" movement in gear systems resulting from inertia.

Center punch—Pointed tool used to indent the surface of hard materials for marking purposes or to form a starting point for drilling.

Computer control—Direction by means of instructions programmed into a computer.

End-effector—Unicorn-One's "hand."

Gear—Toothed wheel or cylinder that meshes with another to transmit motion or to change speed or direction.

Gear ratio—The relation between the number of teeth on one gear and another. The higher the ratio, the greater the reduction in speed and the greater the increase in torque.

Manipulator—Unicorn-One's "arm."

Mobility base—The part of the robot that gives it locomotion.

Radio control—Direction by means of instructions transmitted by radio to a receiver located at the object being controlled.

Robot—Machine that works automatically or by remote-control. Generally assumed to be manlike in shape and function. NASA's space and planetary probes, however, are robots, and they don't look the least like us.

Robotics—The science of robots.

RPM—Revolutions per Minute

Scribe—Pointed tool used to mark hard surfaces to indicate areas to be cut, sawed, or drilled.

Sensor—Device which responds to a stimulus. A photo-electric cell would be an example of a light sensor.

Shaft—Rotating rod or bar which transmits mechanical power.

Solenoid—Electromagnet with a ferrous-metal rod through its core. An induced magnetic field causes the rod to move in or out of the core.

Sprocket gear—Large-toothed gear whose teeth ride in the links of a chain and impart motion to it.

Switch-control—Operation of an electrical or electronic device through the opening or closing of a circuit.

T—Abbrev. for "teeth."

Tap—Screw-like cutting tool designed to cut threads into drilled holes.

Tap drill—Drill bit whose diameter is best suited for use with a particular tap.

Thread—Spiral or helical ridge of a screw, bolt, nut, etc.

TPI—Abbrev. for "threads-per-inch."

Torque—Force that produces a twisting or rotating motion.

Unicorn—*Un*iversal *Con*trollable *Ro*bot.

Using various gearing systems we can easily reduce the speed of a 10,000 RPM motor to an effective 167 RPM, allowing us to use that motor to give real-time motion to the robot's arms.

If we use what is known as a worm gear, we can not only change the speed of the motor—and increase its torque—but also change the direction of the motion. Such an effect can be used effectively in the robot's mobility base.

Various gear assemblies can also change a motor's output from angular (around the axis of the shaft) to linear—that is, from rotary to straight-line, as would be needed in order to push a "hand" forward.

Gears can also be used simply to change movement from one direction to movement in another (say, through an angle of 45°).

The second type of motor used in Unicorn-One is the *stepper motor*. That type of motor responds by turning just a little bit for each electrical pulse it receives. Thus it is possible to move a stepper motor just a fraction of a degree at a time, as might be required in steering the robot. If large amounts of motion are required, multiple pulses are applied.

In addition to the motors, we also use *solenoids* to control the robot's motion. A solenoid is an electromagnet which has a ferrous-metal core. When the magnet is energized, the core—usually a free-sliding metal rod—is either pulled into, or pushed out of, the magnet's coils. Unicorn-One uses solenoids to actuate its grasping members (hands/fingers). If power is applied, the solenoid is actuated and pulls the core inwards. That movement causes the "fingers" to close and to grasp the object in question; the grasp will be maintained until power to the solenoid is cut.

Some solenoids also incorporate gears,

UNICORN-ONE nearing completion. Humans at work give idea of robot's size.

and rotate the gears, and their attachments, through a specified angle, when they are actuated. (They may turn a wheel 45° at a single, momentary command, for instance.)

Finally, we have to consider *limit switches*. Those are absolutely necessary to the well-being of the robot. If we actuate a motor and do not, later, tell it to shut off, we are liable to do damage to the mechanical parts of the robot or even to burn out the motor itself. The limit switch is a device which senses when a mechanical part has reached the predetermined limit of its travel and opens (or closes) the appropriate electrical cricuit to stop the device which is causing the part to move. Limit switches are an inexpensive way to give a measure of control to your robot without your having to pay attention to its every movement.

In addition to the above, we will also use cables and pulleys, anti-backlash gears, bearings, and other mechanical devices to give motion to Unicorn-One.

As we encounter those various components in the construction of Unicorn-One, we'll go into a greater description of their function and operation, and explain why we are using them.

Manipulator construction

The construction of a robot, judging from the available literature, is an expensive proposition, involving skills, materials, and tools not normally encountered in the type of project presented in **Radio-Electronics.** We'll dare to be different here, however, and show you how you can build Unicorn-One using tools you probably have on your work bench and materials that are easy to come by. Even if you have never worked with metals before, we'll provide you with the knowhow to construct a working robot.

The drawings in Fig. 1 show the dimensions for a robot of ideal size. You may, however, decrease or increase those dimensions to suit your budget or needs. Bear in mind that, for radio or remote control, where the power source must be self-contained, the robot's overall weight becomes a very important factor and you may want to deviate from the dimensions given.

The first portion of Unicorn-One that we'll construct will be the manipulators (arms). They will be fabricated from steel rod and aluminum plate, and dimensions and instructions for the metalworking will follow. We'll describe the construction of one manipulator. If you want a two-armed robot, do everything twice. Before you proceed, though, read and heed the following precautions about metalworking:

- Always wear safety goggles or glasses when sawing, drilling, tap-

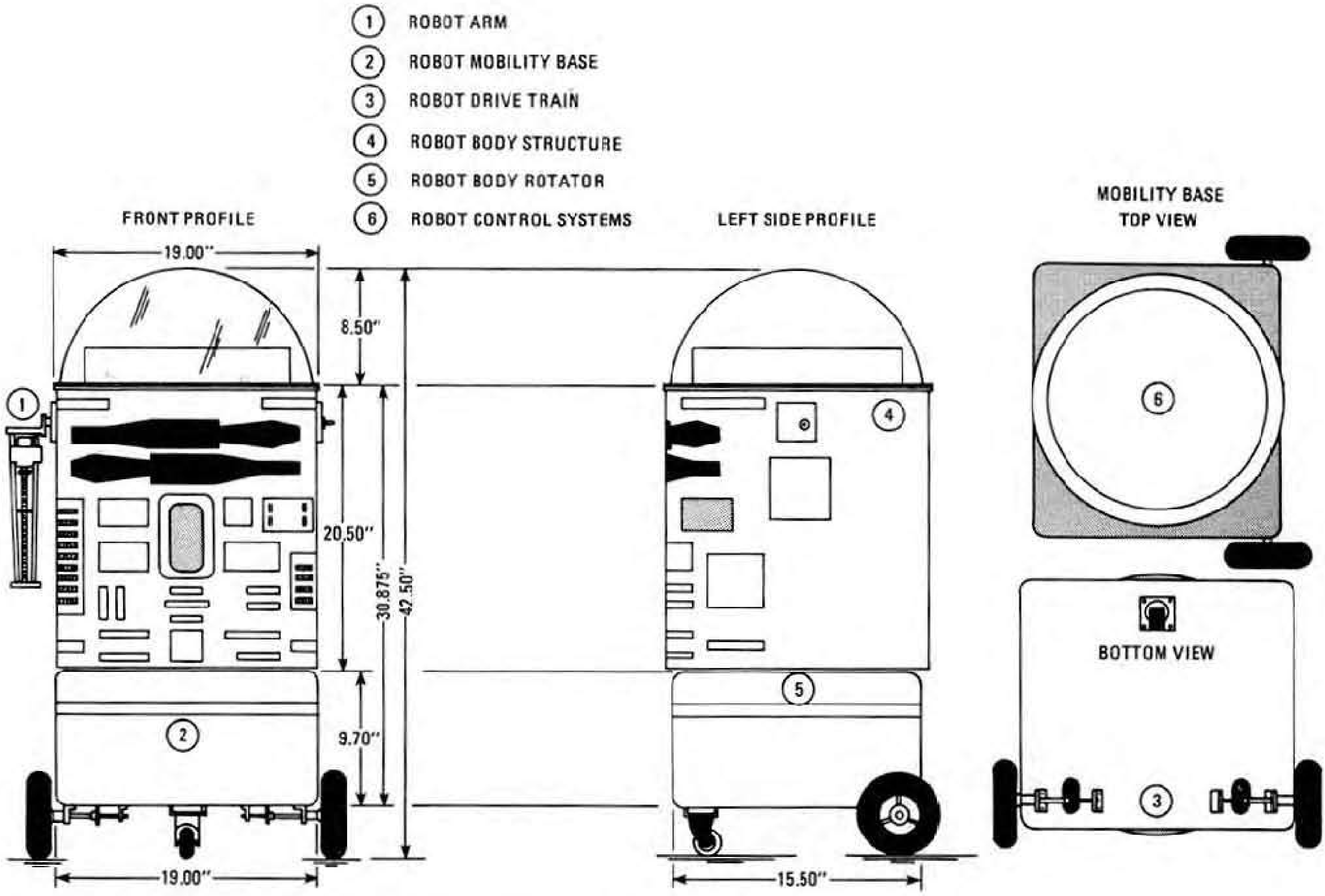


Fig. 1—**DIMENSIONS** of Unicorn-One as described in text. Size is not critical, though, and scale or dimensions may be altered to suit the requirements of the builder.

ping or filing metal (or wood or plastic)

- Never wear ties or loose clothing when operating power tools
- Hold tools properly and make sure pieces being worked on cannot move around

The instructions which follow are intended to be used in conjunction with the diagrams which accompany them. Do not try to rely only on one or the other. If you have a question, the diagrams can probably supply the answer if you study them.

Basically, there are only two different diameter steel rods used to make all the manipulator sections. The cross members are cut from 0.375-in. (3/8-in.) steel rod and the side rods from 0.2497-in. (1/4-in.) material. The threaded steel rod is 1/4 inch in diameter with 20 threads-per-inch. The shoulder and elbow hinges, and the two contractor-bar pivots, are cut from 0.250-in. (1/4-in.) aluminum plate.

The aluminum parts should be made first since they require more work than the rod sections. To keep costs low, use scrap material wherever you can.

The first step is to mark the dimensions of the aluminum part. Do that with a scribe, pointed nail, or even a knife. Don't use pencil, since it rubs off easily. When you cut the part, cut along the *outside* of the lines. You can always file off excess, but it's impossible to put back a little bit too much you removed while cutting. Use a vise to hold the piece steady and use a

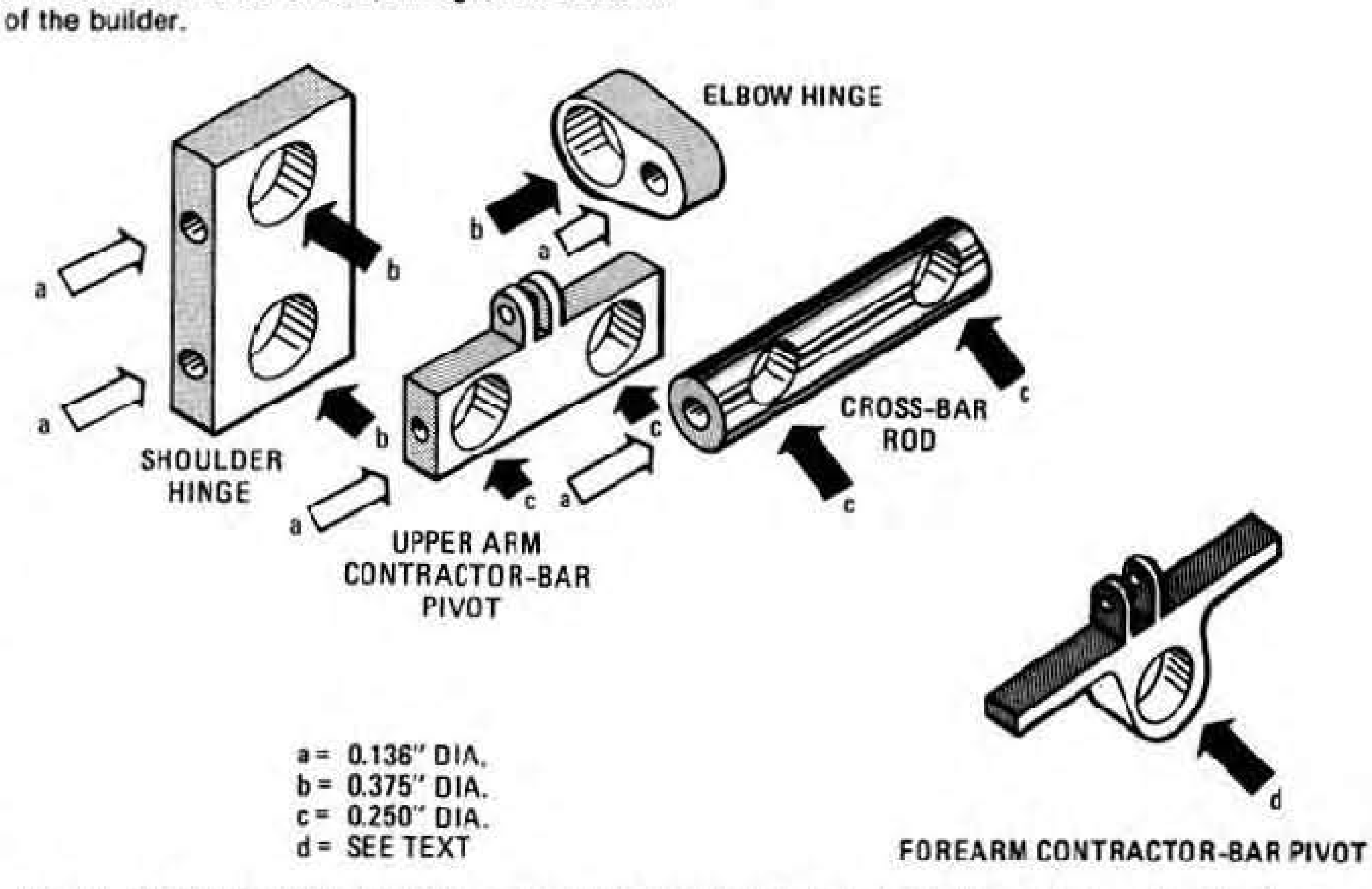


Fig. 2—**DETAILS** of the aluminum parts which must be fabricated. Steel cross-bar rod is also shown as an example. Note that there are several different versions of this part.

hacksaw blade with 24–32 teeth-per-inch to give a smooth cut.

The shoulder-hinge sections are two rectangles, 1 × 1.4 inches, drilled to accept two 3/8-inch rod sections (Figs. 2 and 5). There are two ways by which the steel rods can be secured to those hinge sections: a 1/16-inch hole can be drillled through each for use with roll or dowel pins, or a No. 44 bit (.086 inches) can be used to make a hole which can be tapped for a 4-40 machine screw. Figure 3 shows some of the taps and tap drills that can be used in the construction of the robot.

For the elbow hinge (Fig. 2), outline the part on the aluminum plate and, using a punch, mark the places where holes will be drilled. Saw out a rough rectangle and drill the .375- and then the .136-inch holes. With the holes drilled, the part can be cut and filed down to the proper size.

The two contractor-bar pivot parts (Fig. 2) require a little more work. Again, cut the parts roughly to size (see Figs. 2 and 5). As in the shoulder-hinge pieces, either a dowel pin, or a 4-40 machine

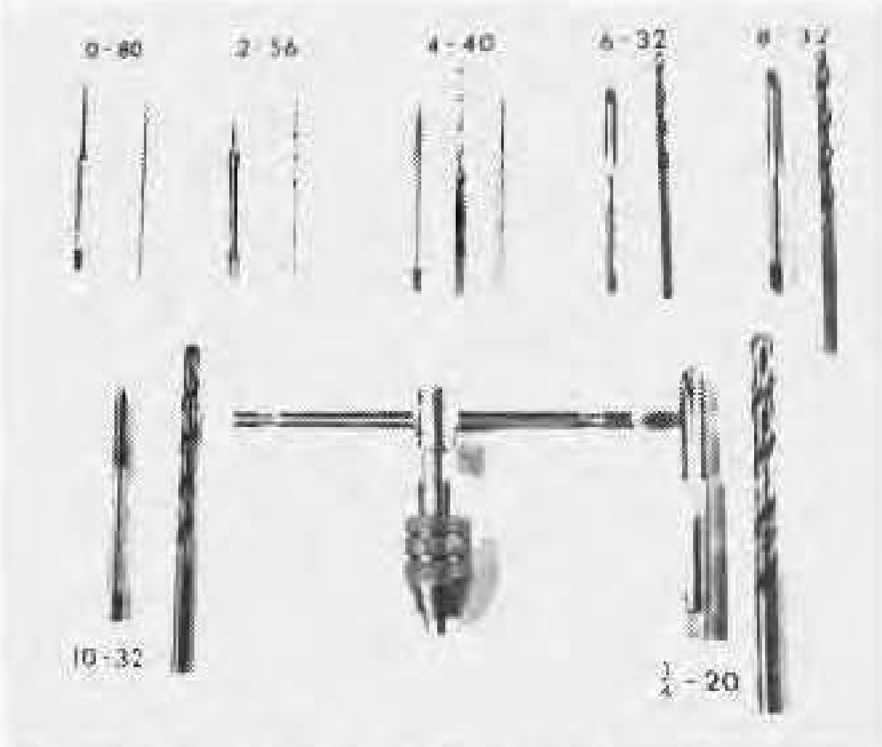


Fig. 3—TAPS AND TAP DRILLS. First number indicates size; second, threads-per-inch.

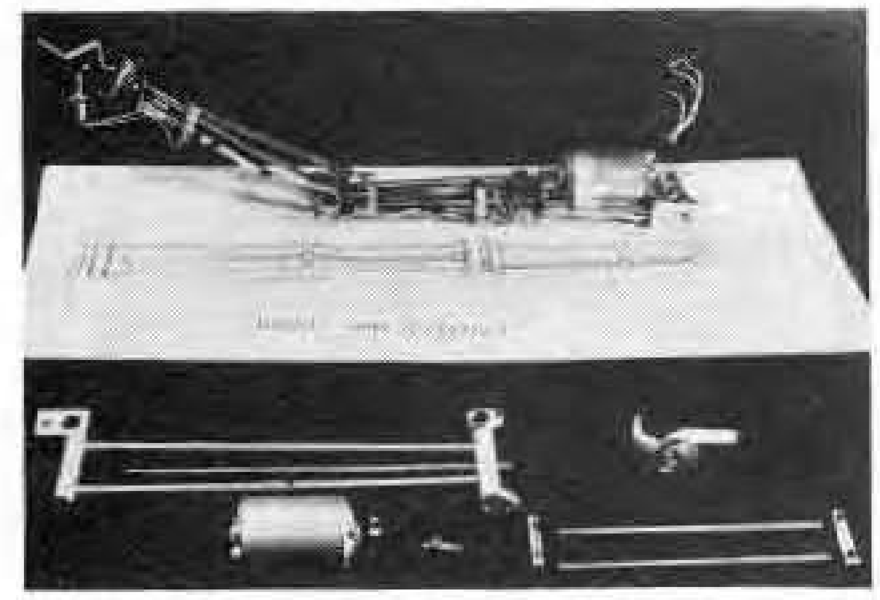


Fig. 4—MANIPULATOR ASSEMBLY. Finished unit and separate pieces are facing opposite ways.

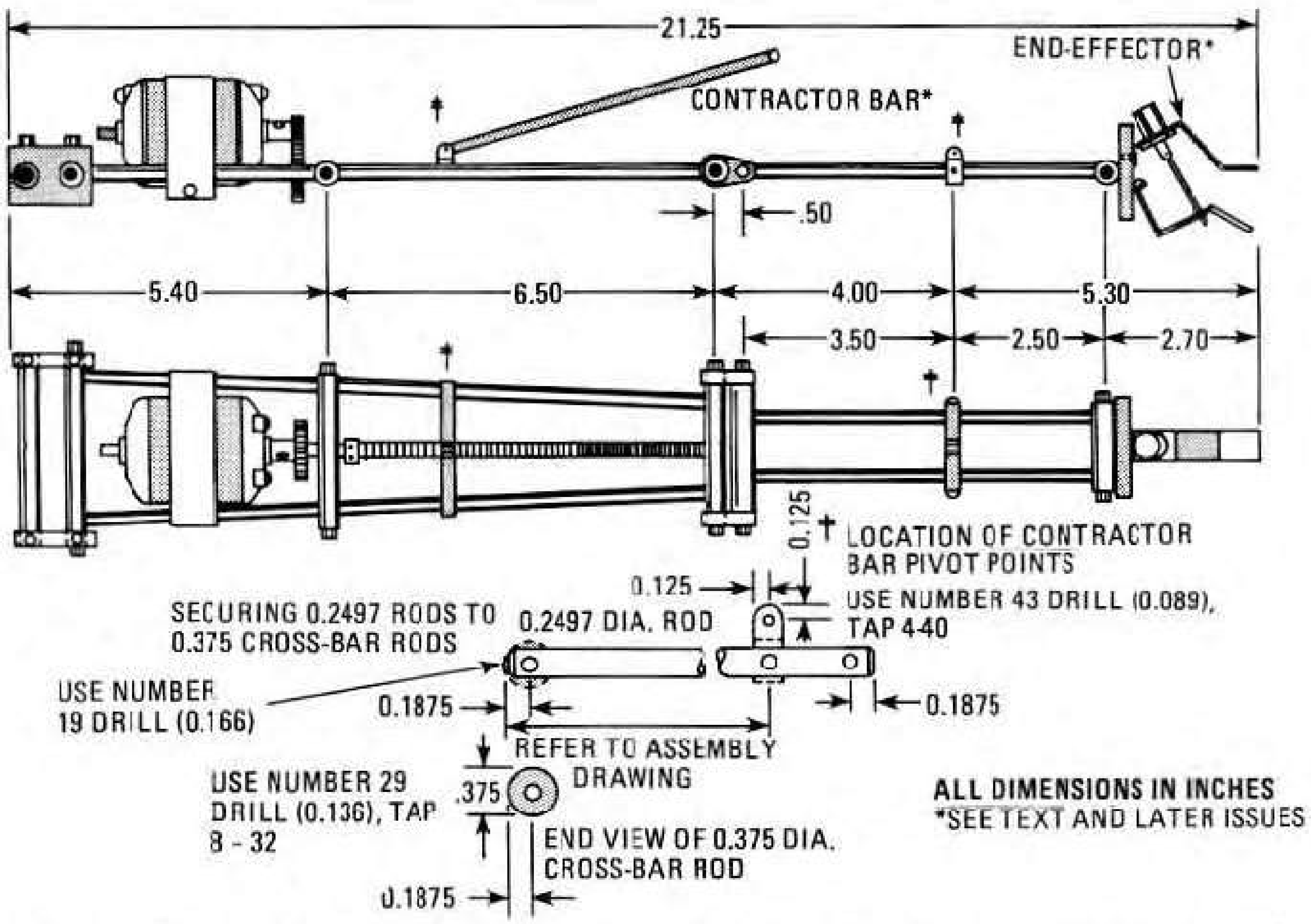


Fig. 6—SIDE AND TOP views of the assembled manipulator. End-effector and contractor-bar will be covered in the next installment.

screw, may be used to provide the pivot support. The upper-arm pivot part has a tapped 1/4-20 hole for the 1/4-20 threaded rod used to provide elbow action. That hole may be made either with a #7 bit (.207-in.) and tapped to 1/4-20 or drilled out slightly larger—.413 in. minimum—to accept a threaded insert, which will give a smoother action. The latter approach is preferred, but the former will give satisfactory results, provided the work is done with care. Both pivot parts should be carefully cut and filed to shape.

To prepare the six steel cross-bar rod sections, cut each length slightly longer than called for. There will be two 3.25-inch sections, two 2.6-inch sections, one

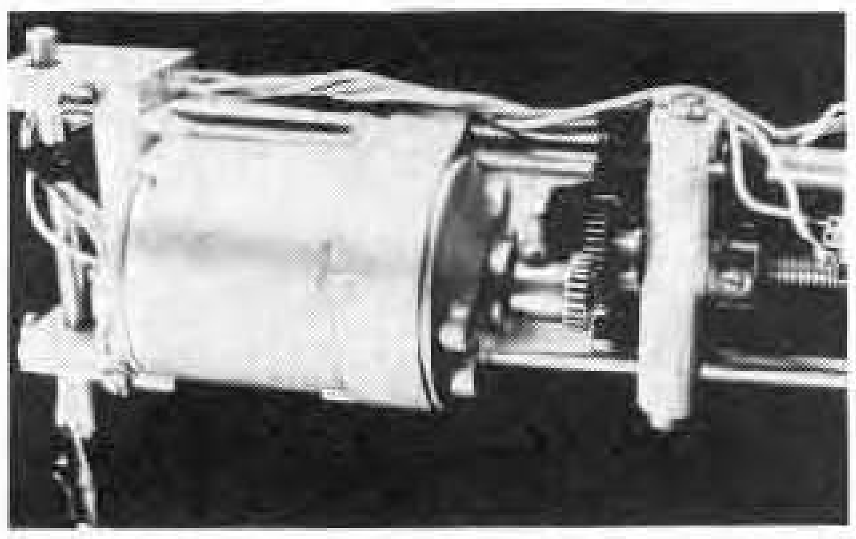


Fig. 7—MOTOR AND GEAR arrangement used to drive threaded rod, as described in text.

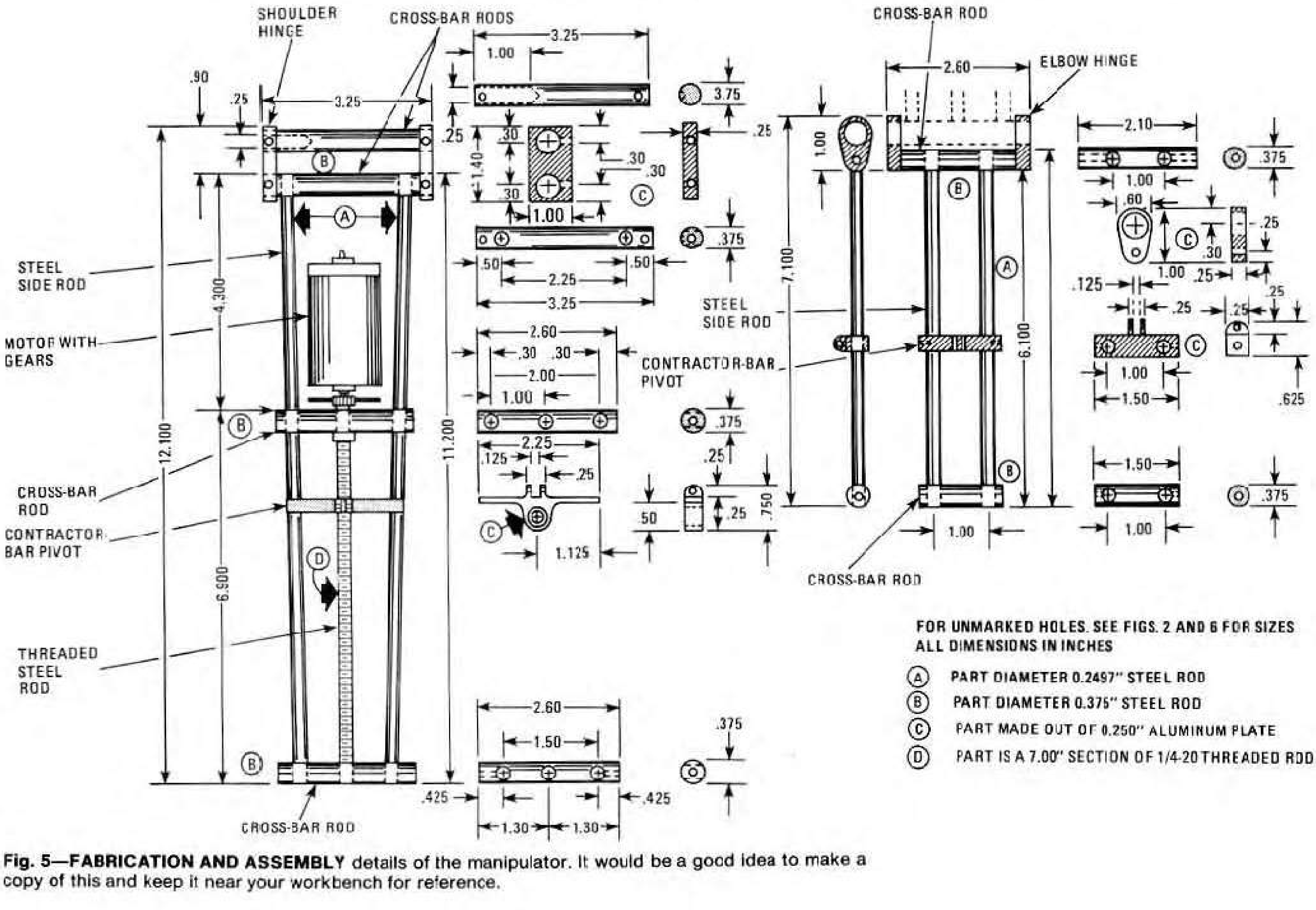


Fig. 5—FABRICATION AND ASSEMBLY details of the manipulator. It would be a good idea to make a copy of this and keep it near your workbench for reference.

PARTS LIST

Item	Size	Quantity	Supplier's part no.	Supplier
Steel rod	0.2497 in. diam.	72 in.	SR 500	Ⓐ
Steel rod	0.2497 in. diam.	72 in.	SL-14	Ⓑ
Steel rod	0.375 in. diam.	36 in.	SR 375	Ⓐ
Steel rod	0.3497 in. diam.	36 in.	SI-33	Ⓑ
Sheet aluminum	0.0625 in. thick	6 x 12 in.	SA 625	Ⓐ
Sheet aluminum	0.250 in. thick	1 x 18 in.	SA 250-18	Ⓐ
Sheet aluminum	0.250 in. thick	1.5 x 6 in.*	SA 250-9	Ⓐ
Threaded insert	OD 0.413 in. TPI ¼-20	2	TI 1420	Ⓐ
Threaded rod	¼-20	14 in.	TR 25020	Ⓐ
Threaded rod	¼-20	14 in.	TI-7	Ⓑ
Reduction gears	20 T, 0.458 diam. ¼-in. bore, 48-pitch	2	G 20 T-48	Ⓐ
Reduction gears	48 T, 1-in. diam. ¼-in. bore 48-pitch	2	G 48T-48	Ⓐ
Shaft collar	OD 0.50 in. ID 0.2497 in.	4	C 525	Ⓐ
Shaft collar	OD 0.50 in. ID 0.2497 in.	4	C5-7	Ⓑ
Dowel pins	OD 0.0625 in. ⅝-in. long	6	D16-625	Ⓐ
or				
4-40 screws	4-40 x ⅝ in.*	6	Z9-4-40-A10	Ⓑ
8-32 screws	8-32 x ½ in. socket-head screws	44	Z9-8-32-A8	Ⓑ
Elbow motor	12 VDC, ¼-in. diam. shaft	2	P-42,670	Ⓒ

SUPPLIERS:

Ⓐ **The Robot Mart**
Room 1113
19 W. 34th St.
New York, NY 10001
(Catalog $3.00)

Ⓑ **Winfred M. Berg, Inc.**
499 Ocean Avenue
Rockaway, NY 11518

Ⓒ **Edmund Scientific Co.**
101 East Gloucester Pike
Barrington, NJ 08007

The above suppliers have catalogs available upon request.

NOTES: Items grouped together are interchangeable. Items marked with "*" include quantities for end-effectors. Suppliers shown are not necessarily the only source for items indicated.

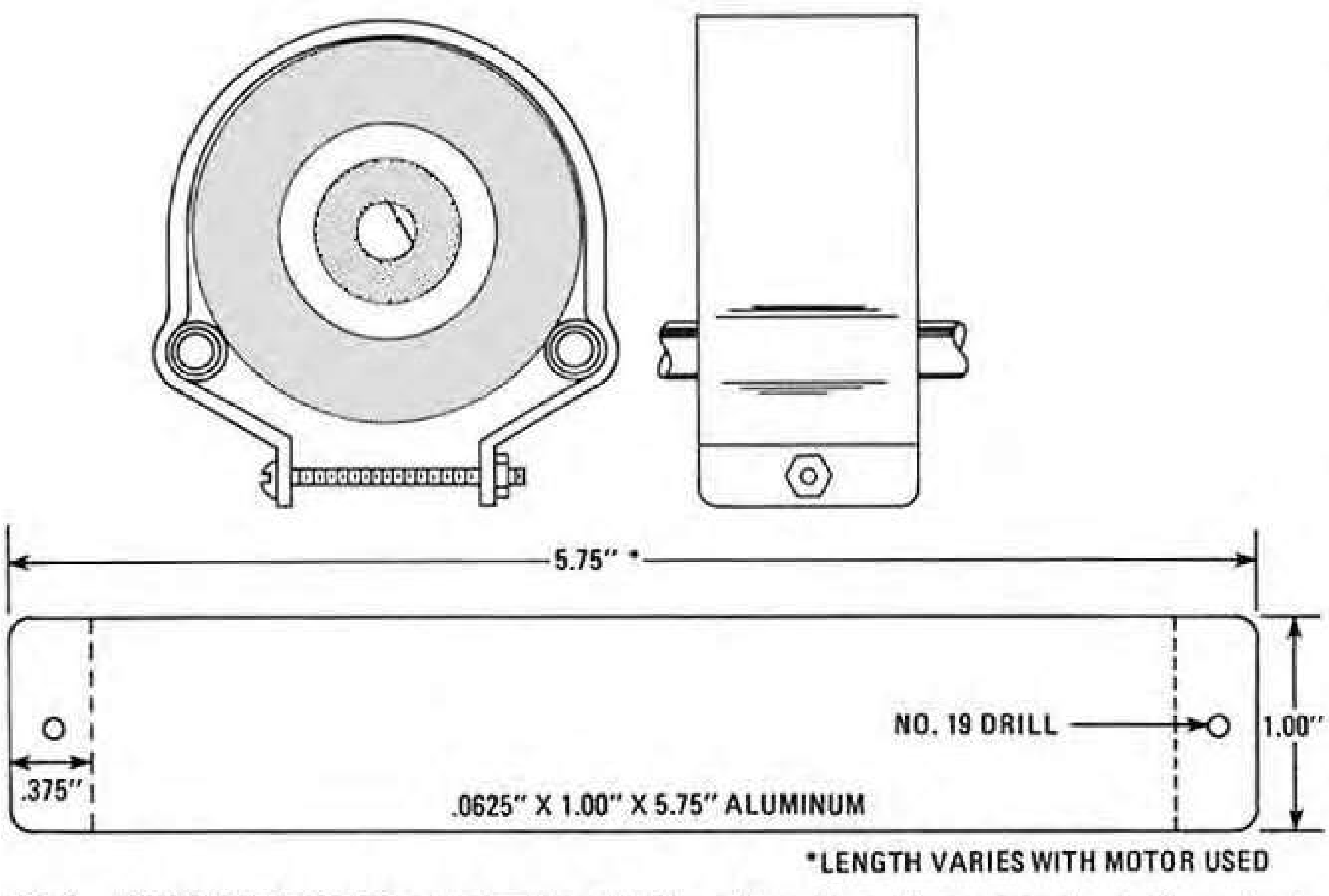


Fig. 8—ATTACHMENT OF DC motor to side rods. Clamp dimensions will vary according to the particular motor used.

2.1-inch section and one 1.5-inch one. Lock each piece into the chuck of a variable-speed electric drill and remove the saw marks by running the drill slowly and filing the rotating rod. When the saw marks have disappeared, angle the file approximately 45° to the rotating stock and lightly bevel the end of the section. Reverse the rod and repeat the procedure on the other end. Next, with the rod still in the chuck, polish its surface with "A" grade silicon-carbide paper. That will give the rod a high-luster finish and remove any remaining surface scratches. The procedure is best carried out by two people.

Carefully drill the rod sections to receive the 0.2497 in. side rods. Each hole drilled must be perpendicular to the rod and parallel to the other hole. If they are available to you, a drill press and "V"-block should be used to make sure of this. To allow the arm to taper, enlarge the holes slightly by "wobbling" a hand-held drill in them.

Figure 4 is a photograph of a fully assembled manipulator (with end-effector) and assembly details are given in Fig. 5. Also refer to Fig. 6. Those should help you to picture what has to be done, and where.

Drill into both ends of five of the six rod sections using a No. 29-bit (.136 in.). Use a punch to mark the center of the rod's diameter and to avoid slippage of the bit. Drill deeply enough to penetrate the .250-inch side-rod holes made previously. One of the 3.25-inch sections—the one which will be used at the top of the arm—gets a .250-inch hole, 1 inch deep, in one end. That will later be used to anchor the arm to the body.

Assemble the two 3.25-inch cross-bar rods and the rectangular shoulder-hinge plate. Use a center punch to mark the rods *through* the .136-inch holes in the plate. Take the assembly apart and use a No. 19 bit (.166 in.) to drill into the rods at the four places marked. Then tap those holes for an 8-32 thread. Also use an 8-32 tap on the .136 in. holes which were drilled into both ends of five of the rods.

Check your work against the diagrams

continued on page 76

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continued from page 41

to make sure that you have not omitted a step. It will be very frustrating if you are halfway through assembling the arm and discover that you have to take it all apart again to drill one small hole that you omitted earlier.

Arm movement

The upper-arm assembly includes a section of 1/4-20 threaded rod which, when rotated by the elbow motor, allows the robot to flex its arm. The threaded rod, which passes through the threaded hole in the pivot slide bar, will move that bar one inch for every 20 revolutions it makes. Using the dimensions given, this will produce a maximum travel of 5.5 inches. A motor turning at 6600 revolutions per minute would be required to flex the elbow through 90° in four seconds.

The most readily available motor, however, turns at 10,000 RPM and would make that action too fast. If we add a one-inch diameter, 48-tooth gear to the threaded rod, and a 1/2-inch, 20-tooth gear to the motor, we reduce the effective speed of the motor by 50% and can achieve full elbow action in a bit under ten seconds. Figure 7 illustrates that arrangement. Note that the threaded rod has a collar secured to it by a set screw. The collar prevents the rod from being pulled upward by the motor.

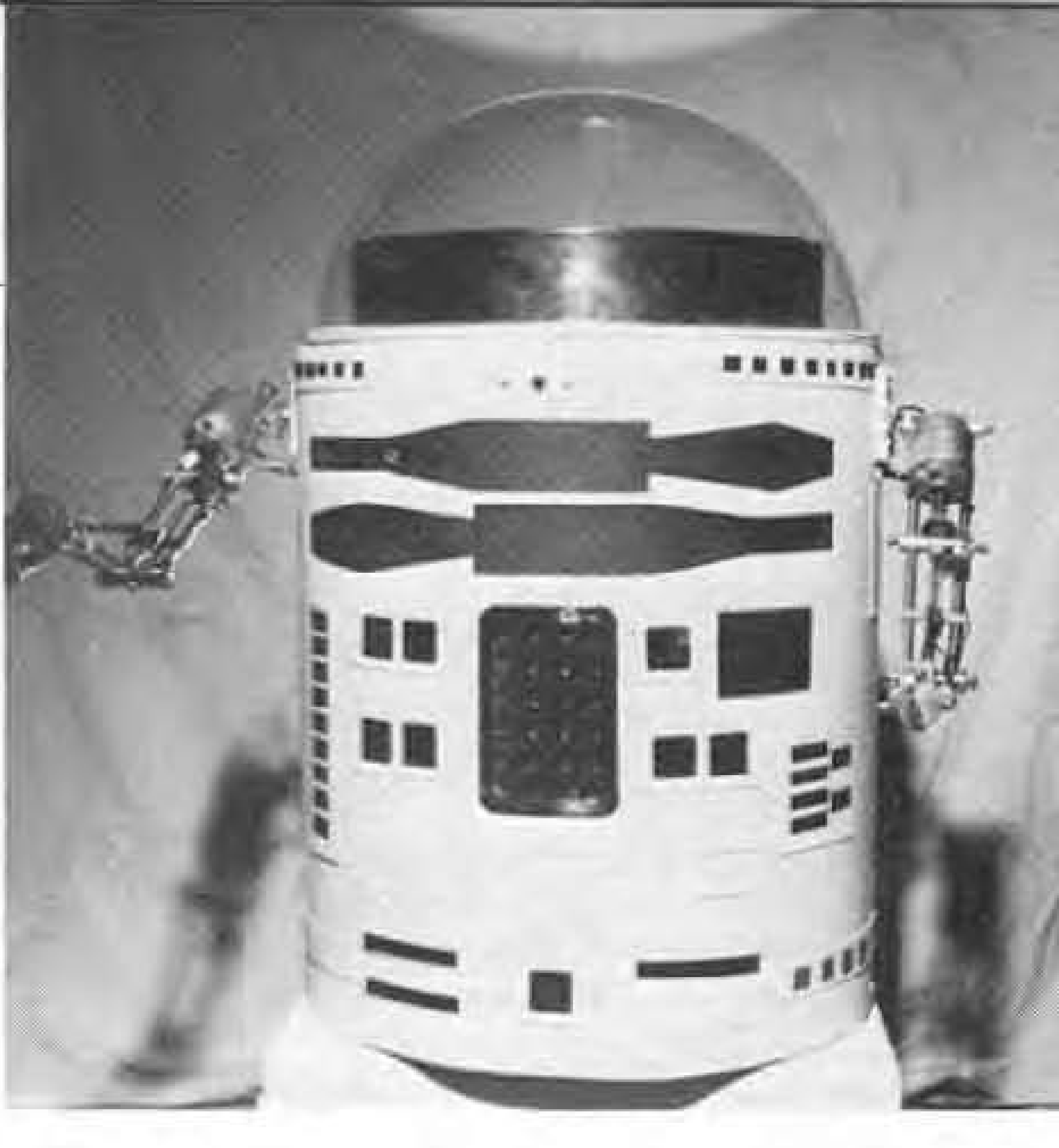
Figure 8 shows a clamp joining the motor and the side rods of the upper arm. That clamp is made from a piece of 1/16 x 1-in. sheet aluminum flared to accept an 8-32 bolt which applies tension to hold the motor in place.

While the preceding may sound somewhat complex at first reading, it *can* be done and will yield a perfectly workable robot arm. You are encouraged to use surplus sheet metal, rods, and gears to keep costs down. For convenience sake, however, a list of components and their sources is shown in the parts list.

The next part of this series will describe the assembly of the manipulators and will cover the construction of the robot's end-effectors (hands). In addition, we will go into the electrical wiring of the manipulators.

Should you have a question about any part of this series, the author may be reached in care of **Radio-Electronics.** Please enclose a self-addressed, stamped envelope with your inquiry to insure a prompt reply. **R-E**

UNICORN-1 ROBOT



Part II—By the end of this section, your robot's arm will be operational. Here are instructions for completing the arm, and for building several types of hands.

JAMES A. GUPTON, JR.

UNICORN-ONE IS A ROBOT THAT YOU CAN build for between two- and-four hundred dollars, depending on your ingenuity and scrounging abilities. It is fully mobile and has the ability to use its arms and hands. It can be controlled by a cable link to a console, by radio control from a console, or in conjunction with a computer.

The first part of this series described some of the components used in the robot's construction, and covered most of the assembly of its *manipulator(s)* (arms).

In this installment we will complete Unicorn-One's manipulators and build its *end-effectors* (hands). From time to time we will present you with certain options that you may or may not want to include in your version of the robot.

Remember that one of this project's objectives is to build a working robot, but at a reasonable cost. When you start adding frills—which *you* may consider necessities—that cost is going to go up. It might be wisest to start with the essentials, to prove that what you have set out to do *can* be done, and to add the extras later. Unicorn-One was designed with that plan in mind and all the options described—as well as most extras that you'll think of yourself—can be added afterward, with no major alterations to the robot already constructed.

Completion of manipulator

The last part of the manipulator to be fabricated is the *contractor-bar* (we saved the easiest for last). That is simply a bar of aluminum $1/4 \times 1/2 \times$ approximately 6 inches long. The actual length will depend on how far you want the elbow to bend, but we've found that 6 inches is a good size to work with. Use a No. 33 bit to drill a hole close to each end of the rod so it may be connected to the rest of the arm with No. 4-40 screws at the two contractor-bar pivot pieces. See Fig. 9 and Fig. 6 (part 1, last month) for details.

At this point you are probably anxious to see how (and whether) the elbow action of the manipulator works. Before you power it up, though, there is one more step that must be taken. If you were to turn on the mechanism now there is a very good chance that you would unintentionally allow the threaded rod to travel too far . . . and jam. That could prove extremely embarrassing.

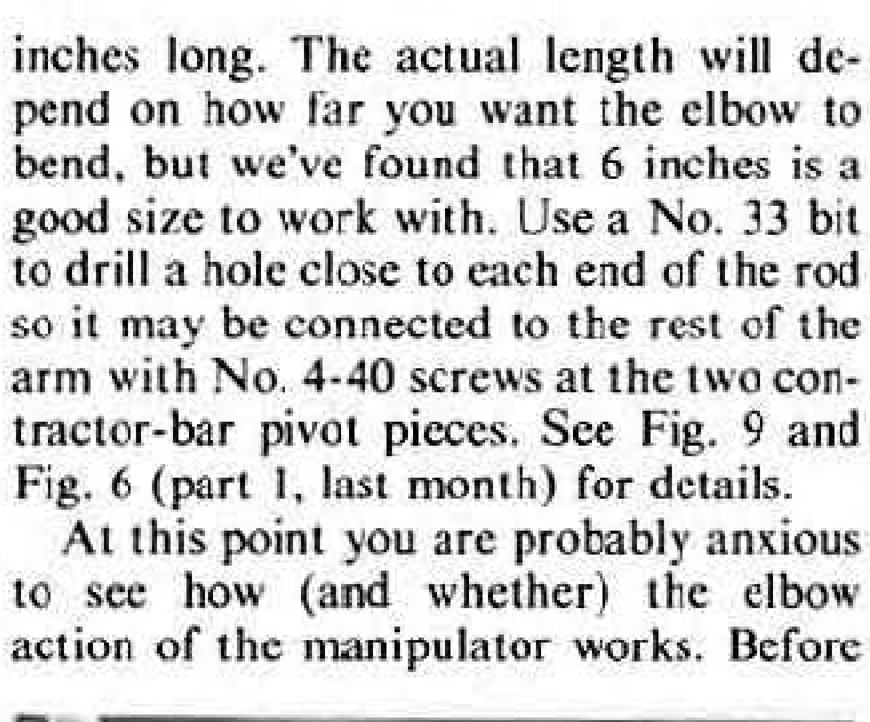


FIG. 9—MANIPULATOR, showing contractor-bar and its attachment to the two pivot-pieces.

To prevent jamming from taking place, we have to install *limit switches*. Those are lever-type snap-action switches that are placed so that power to the elbow motor will be cut when the part in motion reaches the desired limit of its travel.

Both upper- and lower-limit switches are used to protect the mechanism during motion in either direction. If power is applied to the elbow motor through one of the limit switches, the threaded rod will turn and cause the forearm to move up or down. When it has gone as far as it can, it will contact the limit switch and stop the motor.

Since we are using DC motors, reversing the current flow in the windings (connecting the power source "backwards") will make them turn in the opposite direction. Therefore, to make the arm move the other way, the other limit switch supplies the motor with current of the opposite polarity.

Almost any size lever-type, N.C. (Normally-Closed) snap-action switch may be used, as long as there is room to mount it. There is no firm rule as to where the limit switches must be located—the objective is to place them so that they will be turned on by some moving part of the arm in time to stop its motion before damage occurs.

Figure 10 shows one possibility for the placement of the upper- and lower-limit switches. Here, the upper-limit switch is attached to the side rod so that its contacts are opened when it is contacted by the upper pivot hinge. The lower is placed so it will contact the side rod when the arm is lowered and the side rod and contactor-bar are nearly parallel. There are other ways of achieving the same results, of course.

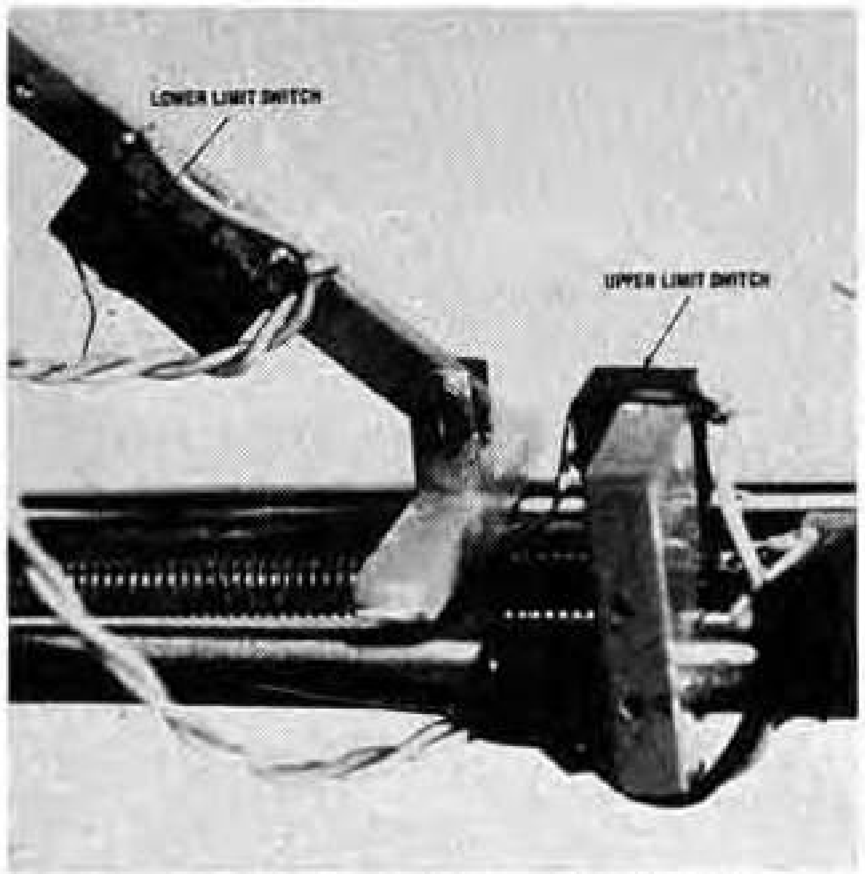


FIG. 10—LIMIT SWITCHES attached to contractor-bar and aluminum block on side rod.

There are two things to bear in mind when placing the limit switches. First, make sure that positive contact will always be made and that there is no possibility that the switch can be turned on accidentally. Second, when taping the switches' wires (and those of the other electrical parts, such as the motors) in place, take care that the tape and wires do not impede the action of any of the moving parts.

The wiring of the limit switches, end-effectors and motors will be covered in some more detail toward the end of this section.

End-effectors

An arm is of little use without a hand at the end of it, so we will present two elementary, but serviceable, types of end-effectors for you to choose from and give you the option of constructing a more complex (and expensive) one, should you so desire.

The two basic hand types we'll describe are the *finger* and the *claw*. Your robot, being ambidextrous, can actually have one of each, using one for one purpose, and one for another.

The grasping action of both types of hand is provided by solenoids—electromagnetic coils with rods through their centers. When a current is passed through the coils, the rod is either pulled into them or pushed out of them. If that rod is connected to part of the hand, the hand will close (in our case) when power is applied to the solenoid. When power is cut, the hand opens by means of a spring which is either part of the solenoid or part of the hand mechanism itself.

Selection of the solenoids is not critical. There are three conditions which must be satisfied: voltage, size, and degree of travel.

The solenoids should be rated to turn on with 12 volts since the robot will almost certainly be using a self-contained 12-volt storage battery when it is operating under its own power. The size of the solenoids will determine the strength of its grip. You may want to use a stronger solenoid in one hand than in the other to allow the robot to perform tasks requiring different degrees of delicacy. As for the degree of travel (the distance of the solenoid's rod can move) we've found that a ½- to-¾-inch rod allows the hand to open far enough for most applications.

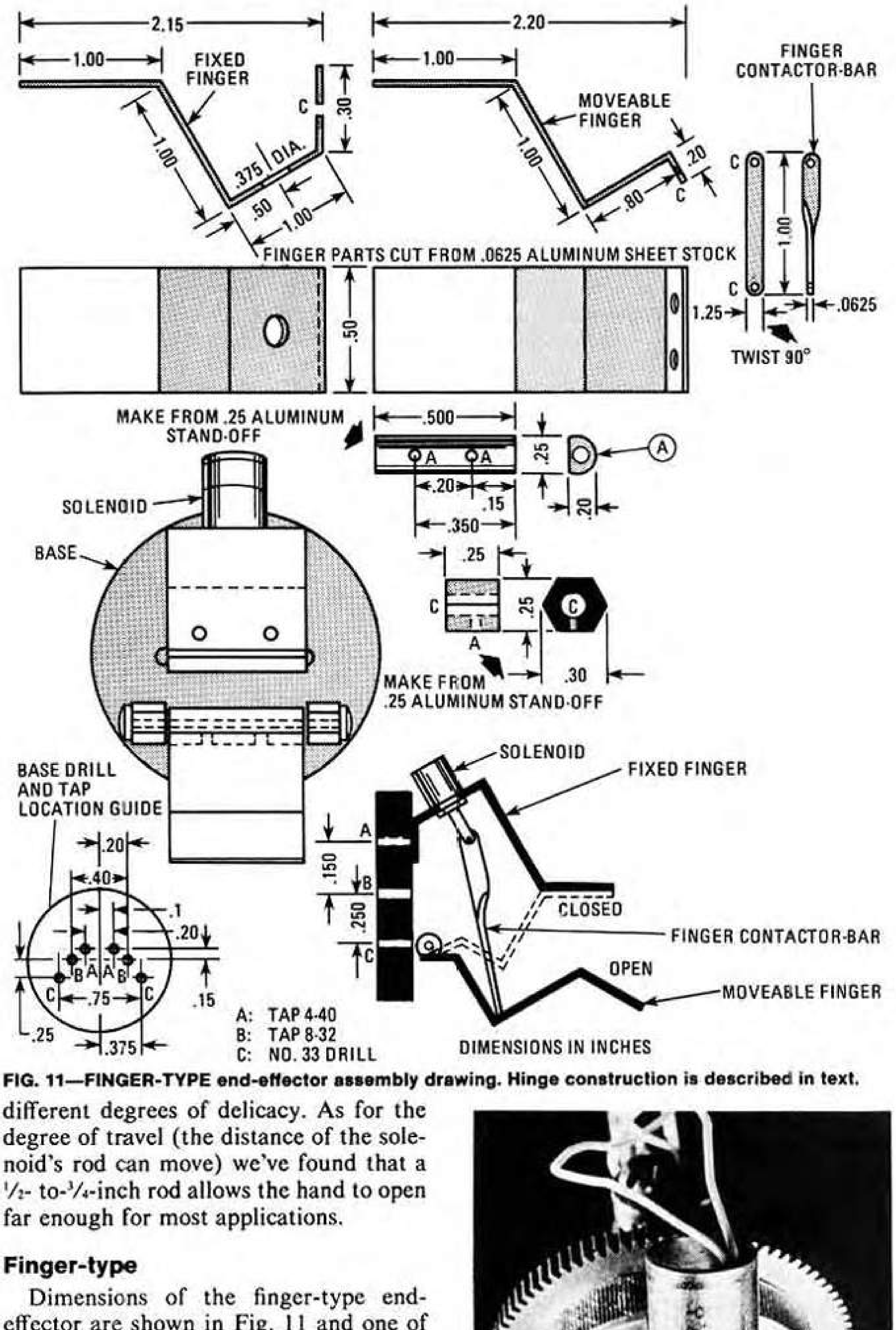


FIG. 11—FINGER-TYPE end-effector assembly drawing. Hinge construction is described in text.

Finger-type

Dimensions of the finger-type end-effector are shown in Fig. 11 and one of the completed units in Fig. 12. The material used for that part is $^1/_{16}$ × ½-inch sheet aluminum. The fixed (upper) finger is made from a piece 3.3 inches long and the movable (lower) finger, from a 3-inch one. The angles should be formed by placing the metal in a vise and bending as evenly as possible. Use a hammer to give uniformity to the surface.

The *finger contractor-bar* is made of $^1/_{16}$ × ¼-inch aluminum, drilled at both ends. The length depends on the solenoid's travel. As shown in Fig. 11, a half-twist is put into that bar. One end of the bar is attached to the solenoid, which is mounted on the outside of the fixed finger, and the other is inserted through a slot sawed in the outside edge of the movable finger and secured with a cotter pin or similar device.

The movable finger is attached to the hinge (refer to Fig. 13) by two No. 4-40 screws. The hinge itself is supported at

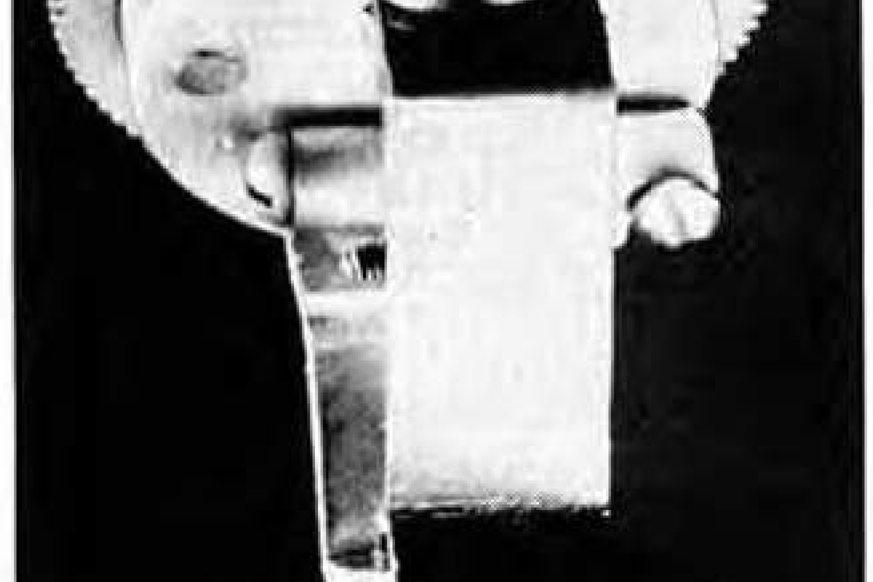


FIG. 12—COMPLETED FINGER-TYPE end-effector. Gear is non-functional, but adds to appearance.

one end by a ½-inch diameter piece made from a section of an aluminum stand-off with a long No. 4-40 screw acting as the hinge pin. The finger/hinge assembly is

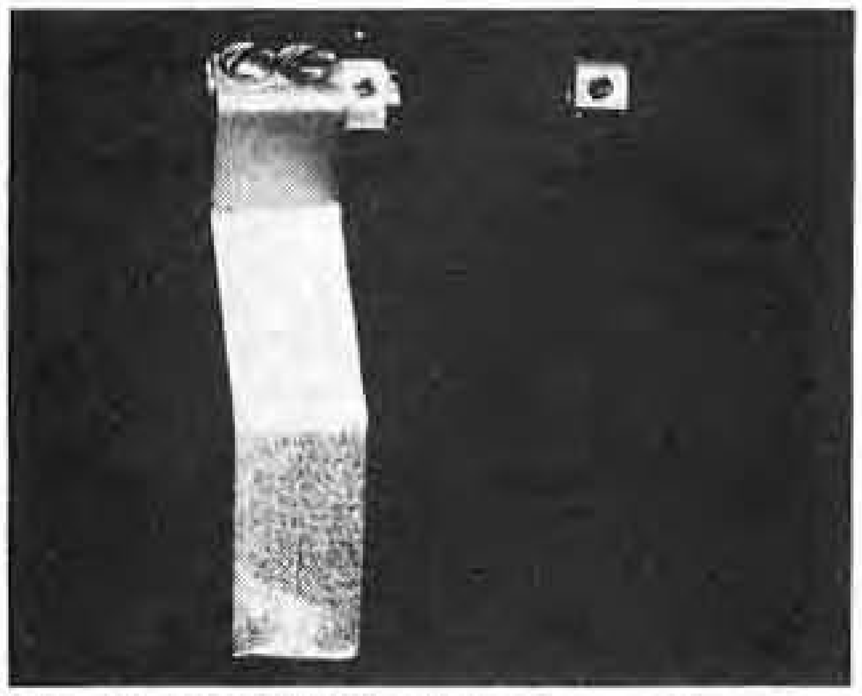


FIG. 13—DETAILS OF HINGE used in finger-type end-effector assembly.

fastened to an end-plate one inch or more in diameter and ½ inch thick using No. 8-32 screws and that, in turn, is mounted to the last cross-rod of the manipulator's forearm. The original Unicorn-One used a non-functional gear to build up the end plate and to give the robot a touch of class.

The finished end-effector may be fixed horizontally, vertically, or at any angle in between. Its position depends on the use to which the member will be put.

Claw-type

For heavier-duty applications, you might want to use a claw-type end-effector; that type of hand is shown in Figs. 14 and 15. On ¼-inch aluminum plate, use a scribe to mark the outline of the two sections. Rough-cut the pieces, taking care to keep to the outside of the outline to allow a margin for error.

Using a hacksaw on the inside angles of the claw may prove to be difficult or even impossible. Instead, try drilling a closely-spaced series of small holes along the *outside* of the part. Then, using a cold chisel, knock it out and file it to shape, along with the rest of the claw.

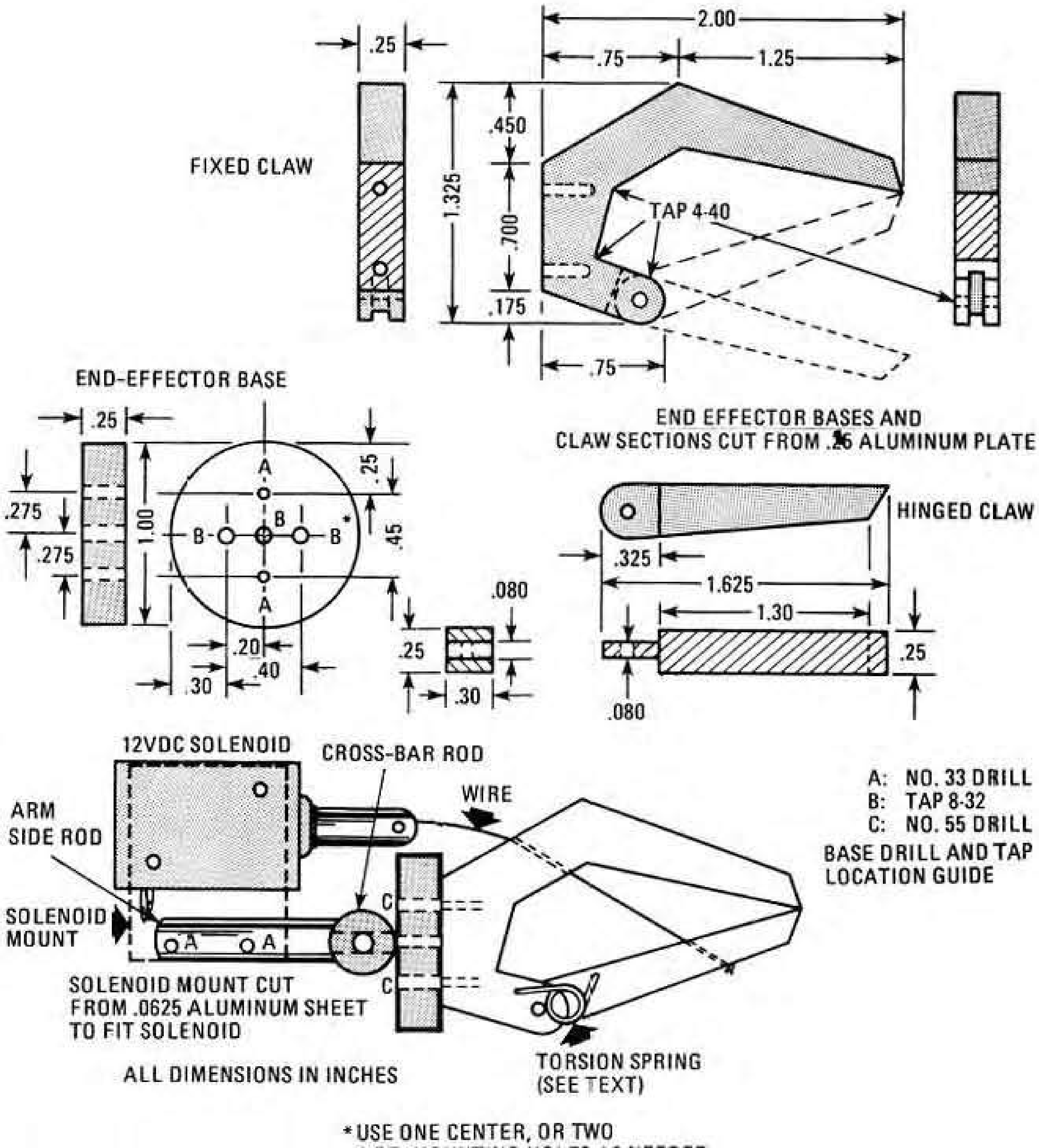


FIG. 14—CLAW-TYPE end-effector assembly drawing. This is a heavier-duty mechanism than the finger-type and you may want one of each.

Drill two small holes through the two claw sections, in the plane of movement (parallel to the flat sides of the claws), to pass the cable from the solenoid, which can be anchored by a screw to the lower

PARTS LIST

Item	Size	Quantity	Supplier's part no.	Supplier
Sheet aluminum	.0625 in. thick	1 X 7.5 in.*	SA625	A
Sheet aluminum	.250 in. thick	1.5 X 6 in.*	SA250-9	A
Sheet aluminum	.250 in. thick	0.5 X 6 in.	SA250-3	A
Solenoid†	Size 50, ½ X 1 in, 12 VDC	1	176801-035	F
Solenoid†	Size 75, ¾ X 1½ in. 12 VDC	1	174610-031	F
Solenoid†	⅔-in. stroke, 12 VDC	1	26	G
Solenoid†	½-in. stroke, 12 VDC	1	L26	H
Solenoid†	"D"-frame, 12 VDC	1	290001-033	F
Snap-action switch	Subminiature roller-lever-type, 5-amp	4	275-017	I
Snap-action switch	Subminiature lever-type, 5-amp	4	275-016	I
Machine screws	2-56 X ⅜	8		
Machine screws	4-40 X ½	11		

SUPPLIERS

A The Robot Mart
Room 1113
19 W. 34th St.
New York, NY 10001
(Catalog $3.00)

B Winfred M. Berg, Inc.
499 Ocean Avenue
E. Rockaway, NY 11518

Ledex, Inc.
Box 427
Vandalia, OH 45377

G Guardian Electric Mfg. Co.
Advertising Dept.
1550 W. Carroll Ave.
Chicago, IL 60607
(Write for list of local distributors.)

H Liberty Controls, Inc.
500 Brookforest Avenue
Shorewood, IL 60431

I Radio Shack
Consult your local telephone directory.

NOTES: Items marked with "*" were already specified in the parts list for Part One of this series. Items marked with "†" are to be selected according to the builder's requirements. Components may also be available from suppliers other than those indicated. Some suppliers have minimum order requirements. Inquire before placing order.

FIG. 15—ASSEMBLED CLAW-TYPE end-effector. Piano wire may be used to connect solenoid and lower portion of claw.

claw. A small hole should also be drilled into the *flat* side of each claw into which the ends of the spring which will keep the hand open when the solenoid is not turned on.

Robot manipulator-claw springs are not an off-the-shelf item in most places, so you'll probably have to make your own. Figure 16 will give you an idea of what you'll need. If you haven't taken apart any clocks recently, you might try using a section of the type of spring used to close

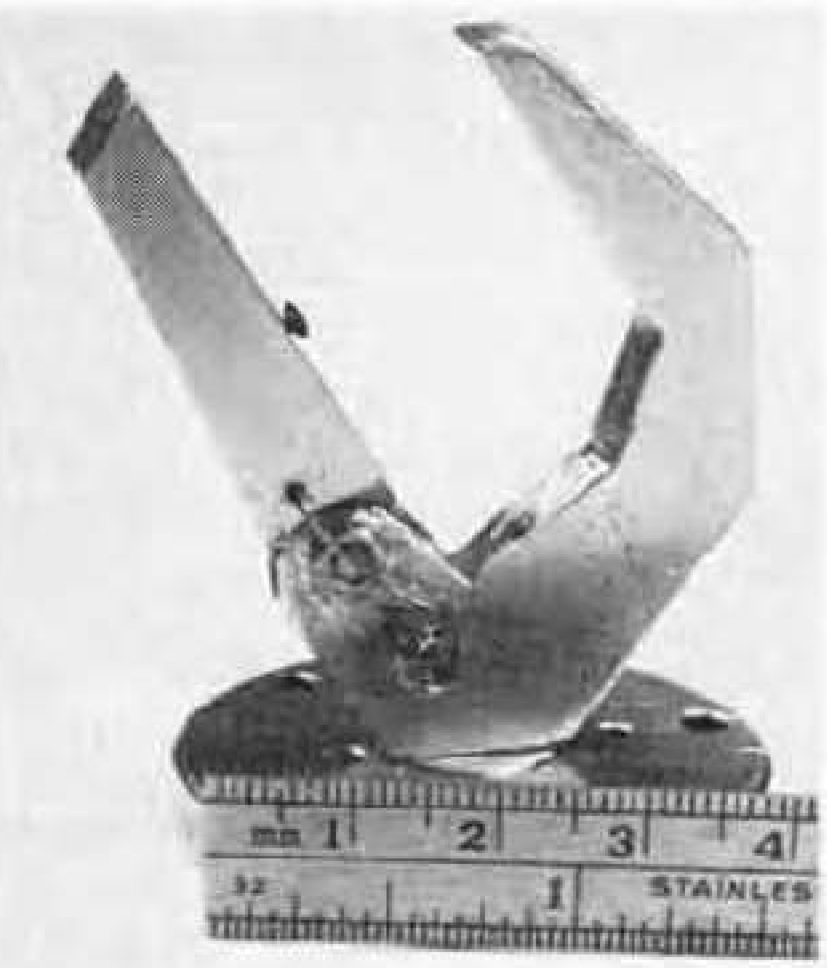


FIG. 16—CLAW-TYPE end-effector showing homemade torsion spring. Text gives details.

screen doors in the summer. Material 1/32-in. in diameter seems to work out well.

The tension of the spring will affect the claw's actions. If it's too strong, the claw will not close properly and the robot's grip will suffer, and if it's too weak, there can be problems with keeping it open. If that sounds confusing, bear in mind that the purpose of this particular spring is to hold the claw *open*, not closed.

Attachment to the manipulator is similar to that for the finger-type end-effector, but you may decide to mount the solenoid (which will probably be larger than the one used for the other) directly on the forearm and feed the cable through to the claw.

You might want to line this hand—or possibly both—with foam rubber or a similar material to give it a better grasp on slippery objects.

A more elaborate type of end-effector is shown in Fig. 17. It also uses the claw-type mechanism but has an additional *degree of freedom*—a term referring to the different ways a joint can move. (Your own arm, for example, has three degrees of freedom: It can twist, move up and down, and move from side-to-side.)

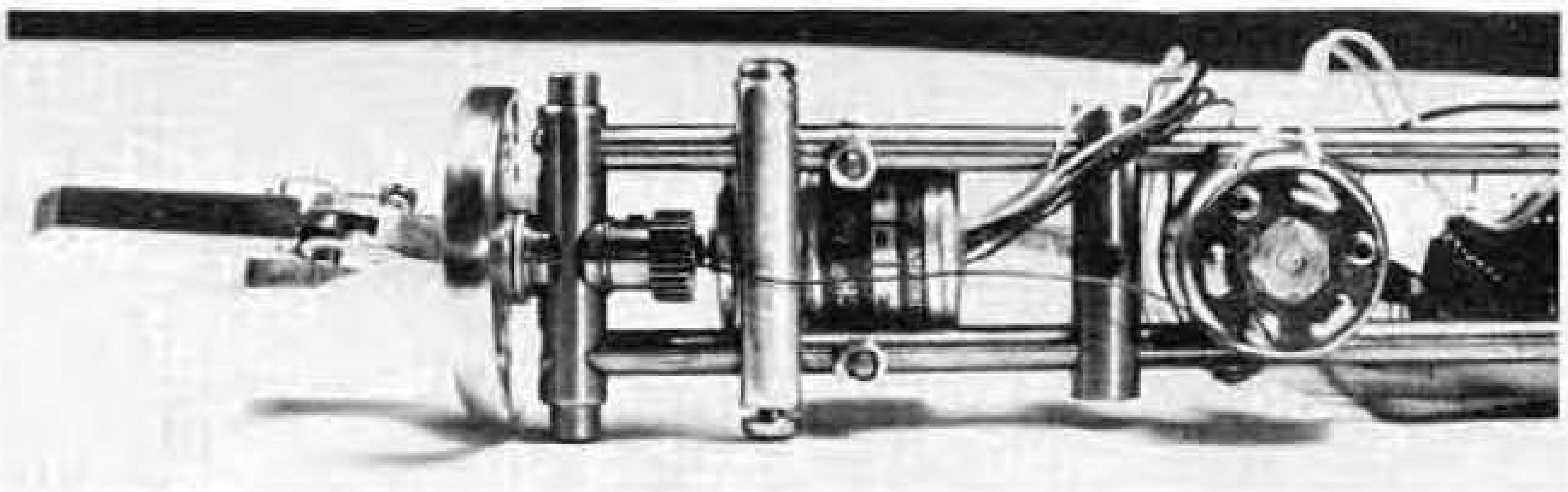


FIG. 17—ROTATABLE end-effector mentioned in text. Stepper motor supplies wrist action.

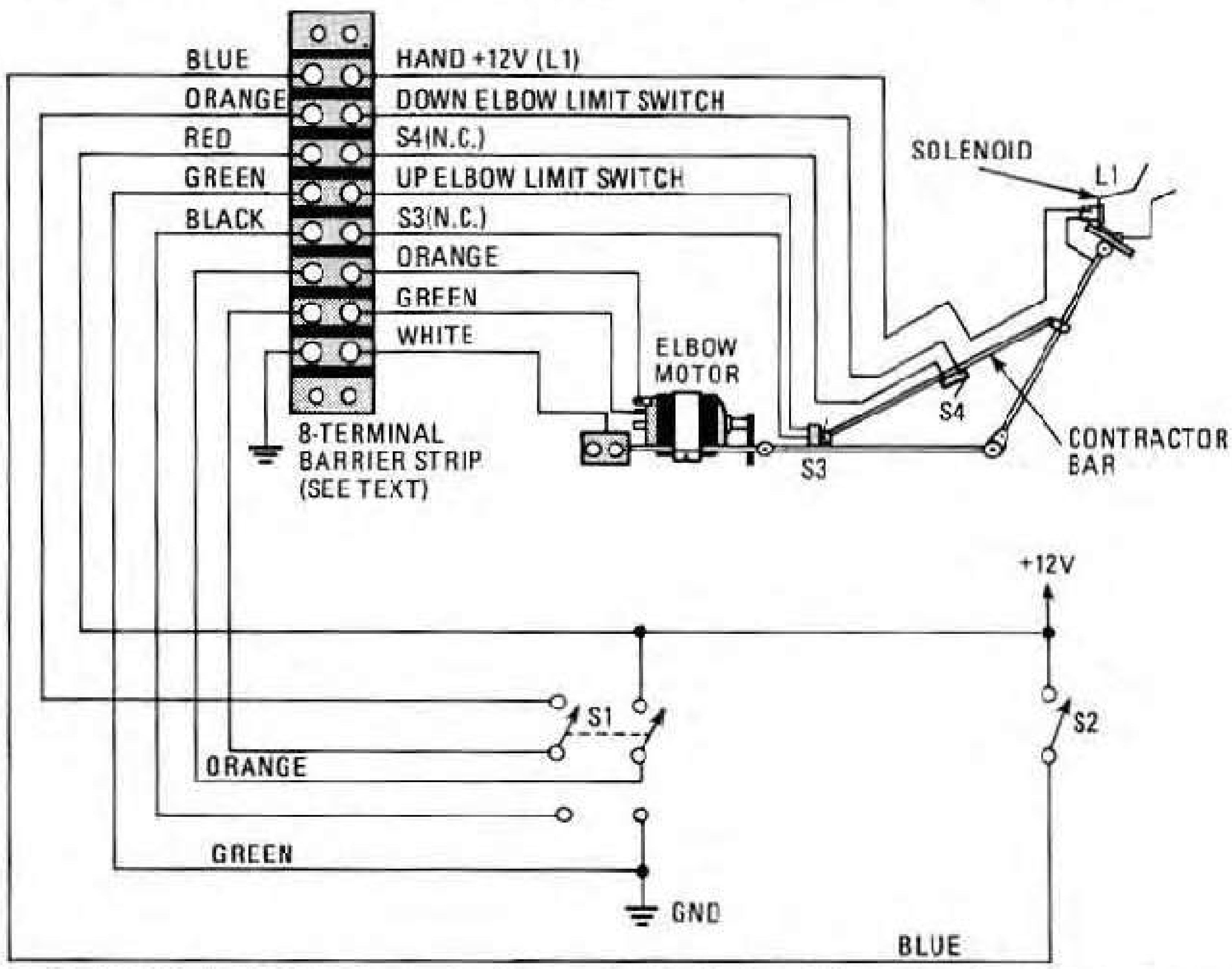


FIG. 18—WIRING DIAGRAM for manipulator and end-effector. Color-code wires in order to avoid confusion.

The added mobility is gained by placing a stepper motor between the arm and the hand. The stepper motor's shaft turns through a small portion of an arc each time a short electrical pulse is applied to it. The result, if enough pulses are applied, is a twist of the wrist—and an added degree of freedom!

Because those pulses are best generated by a digital electronic circuit—which we have not yet discussed—we'll postpone a description of the construction of this type of hand until we start putting together Unicorn-One's electronics. For certain applications, though, it can be indispensible.

Wiring and testing

A wiring diagram for the motor, solenoids, and microswitches, with their associated controls, is shown in Fig. 18. The eight-position terminal strip illustrated is actually part of a 32-position strip, which will terminate all motor and switch connections. Since 32-position terminal blocks are difficult to locate, do the best you can with smaller ones—but allow for at least 32 positions. That will give you several extra positions which you can later use for your own options.

Color-code the wiring to simplify circuit tracing and make sure that everything goes to the right place and that you have electrical continuity.

Now, with the limit switches installed, you can check out the actual operation of the manipulators and end-effectors. In fact, this is the best time to do so. (If you were to wait any longer, and the arm were attached to the body, you might have to do quite a bit of tearing-apart to get to, and correct, any problem that showed up.)

The parts list shows sources of supply used by the author. There are certain to be others, though, possibly more accessible to you. In fact, many of the materials specified can probably be found, in a form close enough to work with, at your local hardware or building-supplies store. Even closer—and more economical—may be your basement or a nearby junkyard.

The next part of the Unicorn-One series will concern itself with design considerations and construction of the robot's mobility base—the section that gets it from place to place. Also included will be details of the main 32-position terminal strip, which will be the heart of the robot's electrical distribution and control system. The design of that section will permit easy changeover, when you're ready, from manual control by cable-connected console to radio control and, later, to control by microcomputer. **R-E**

BUILD THIS

UNICORN-1 ROBOT

Assembling the Legs

Part 3—Every robot should have a way to get from place to place. This part of the Unicorn-One series describes the mobility base, which allows the robot to do just that.

JAMES A. GUPTON, JR.

HAVING ALREADY OUTLINED THE CONSTRUCTION of the robot's arms and hands in parts 1 and 2 of this series, we'll now discuss its *mobility base*—the powered section that allows it to move from place to place.

The mobility base houses the robot's electrical power source, its drive motors, and the heart of its wiring system.

While it may be necessary to purchase some of the components of the mobility base new, there is still a lot of money that can be saved through judicious scrounging. Remember—it doesn't really matter what you use to get something done, as long as it *does* get done and the results are what you need.

We'll present two approaches to constructing the mechanism of the mobility base. The first, which may require some cash outlay, is the one we've found to give the best results. The second, which is more economical, is a bit trickier and not quite as acceptable to the purist. Still, both work.

Figure 19 illustrates the dimensions and external appearance of Unicorn-One's mobility base. Actually, for the sake of economy, the original housing was made using a large discarded electronic chassis, as seen in Fig. 20.

One of the most stylish ways to go is to use Bud aluminum or steel panels, plates and frame sections, which can be ordered through most electronics parts distributors. The parts list shows the designations of the Bud parts required. Unfortunately, this approach, which requires only a little cutting and drilling, can turn out to be fairly costly.

You might, therefore, want to turn to scrounging (a local sheet metal firm might have some odds and ends that could be picked up cheaply), or purchasing material that was not precut. Be sure, though, that the aluminum (if that's what you're using) is *type 5005*—an indication of its strength. You must bear in mind the fact that the mobility base will be supporting at least 30 pounds of the robot's weight and that if it is too weak, the mechanical integrity of the robot will suffer.

Every part of the mobility base skin can be made from aluminum, except for the top. That should be fabricated from 0.125-inch *steel*, both to support the weight of the body and to allow the bearings upon which the body will rotate to turn freely.

The side panels can be made from .0625-inch aluminum, since they will not be responsible for bearing weight. An option is given in the parts list to use four 19 × 7-inch side panels. These are not, of course, the dimensions shown in Fig. 19, but reflect the possibility of your choosing to build a square base, and also the use of a smaller size battery. Actually, the dimensions are not critical. Just make sure that the robot's center of gravity falls within the support points (the wheels) and that there is enough room inside the mobility base for the battery, motors and terminal strip. Be sure to allow sufficient clearance for you to access the battery.

Finally, aluminum angle-bracket, available at hardware or building-supply stores, will do very nicely for the frame in place of more expensive materials.

Access to the mobility base is provided by a hinged plate at the back (Fig. 21). Lay out the interior so that the important parts can be reached through the opening this plate provides. Use the diagrams and photographs in this installment to guide your thinking. There is nothing forcing you to make a carbon copy of the original Unicorn-One. Use your imagination and ingenuity.

A 2½-inch wide curved opening will have to be cut in the top of the mobility base (refer to Fig. 19) to permit wires to be routed between the base and the body. This opening may be located at either the front or the rear of the top section. You should make sure that the wires will not jam in the slot as the body rotates—don't forget to allow slack in the wires for this purpose—and the slot should be edged with some soft material such as several layers of electrical tape, or flexible tubing which has been slit to fit over the cut metal, to prevent chafing of the wires' insulation.

Transmission and drive train

There are three main sections to the "mobility" part of the mobility base. They are the motors, the wheels, and the parts which transmit the action of the former to the latter. The wheels are easy to obtain. The two 6-inch driven wheels can come from an abandoned child's wag-

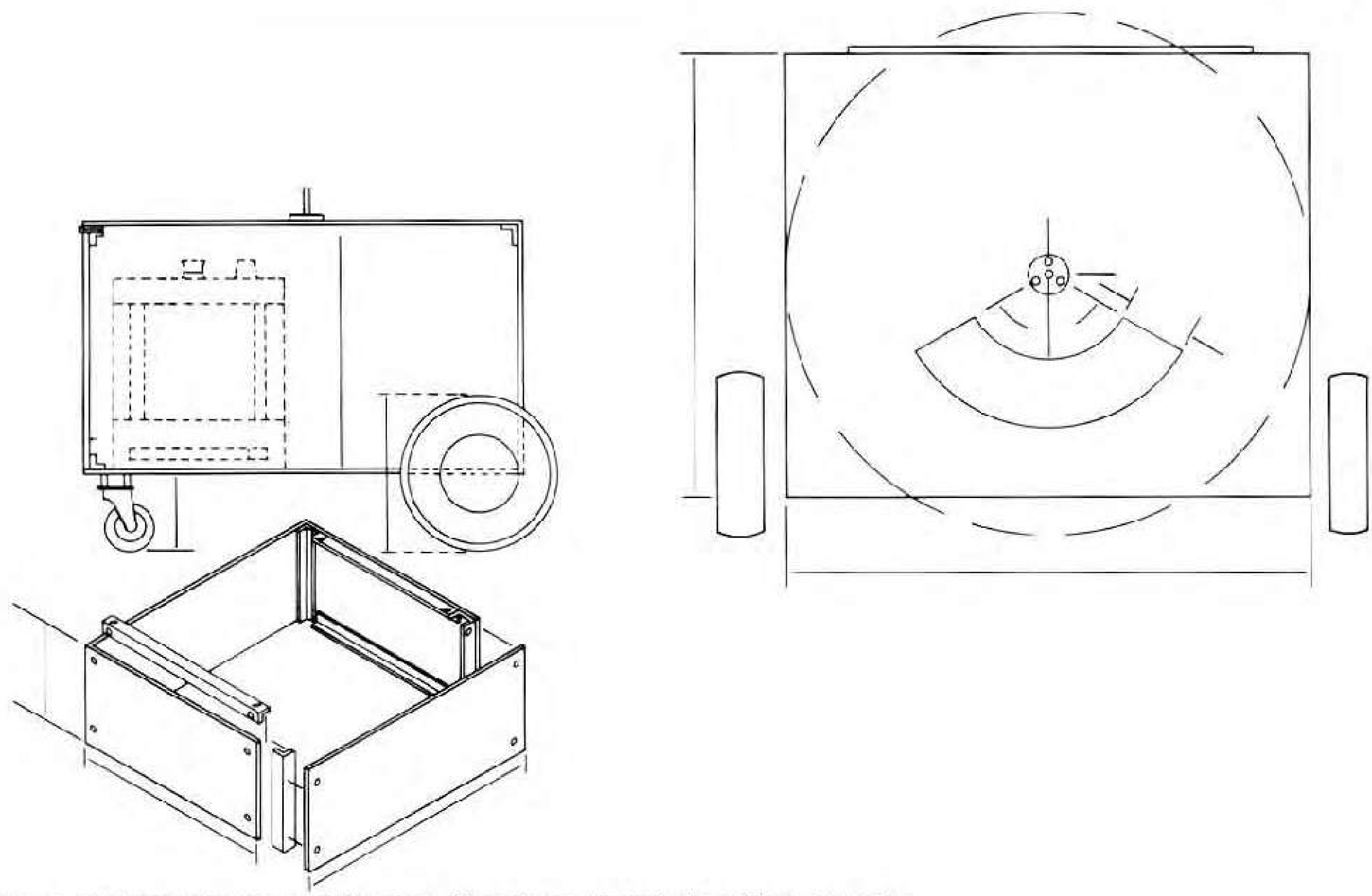


FIG. 19—MOBILITY BASE layout and dimensions. Figures here are for author's prototype—yours may differ (see text). Top plate is made of steel; rest can be aluminum.

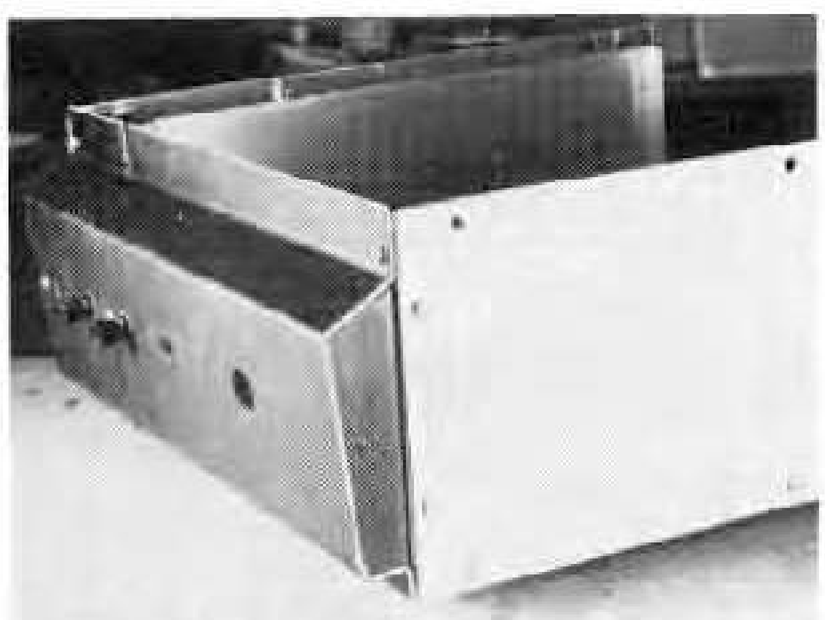


FIG. 20—EARLY VERSION of the mobility base enclosure, built from parts at hand.

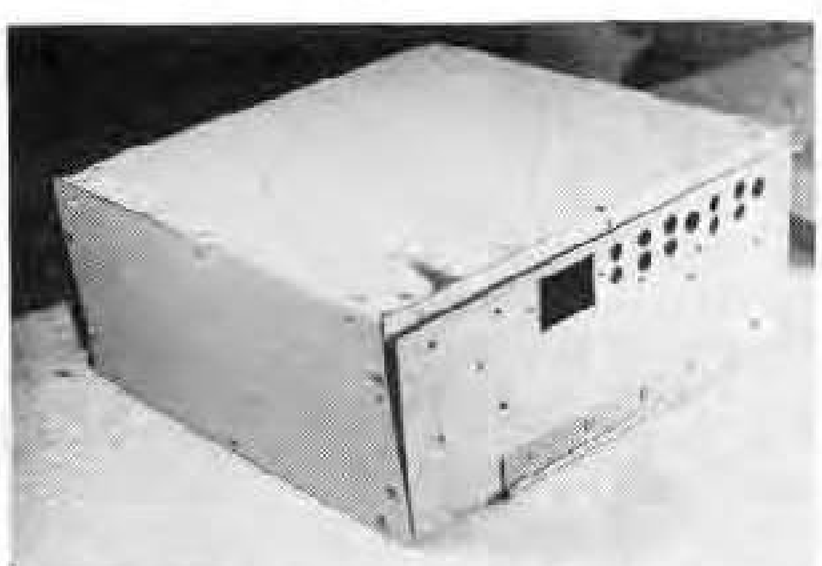


FIG. 21—HINGED BACK PANEL allows access to components mounted inside mobility base.

on or scooter, or from a lawnmower service shop, to name a few sources. The front caster wheel is probably best found in a hardware store.

The preferred motors, used in the first approach, are gear motors which run at a speed of between 20 and 25 RPM. Sources for a 22 RPM motor are given in the parts list. If you elect to go the second route, you can use simpler, higher-speed motors. Again, refer to the parts list.

Figure 22 illustrates a section of a mobility base constructed using the 22 RPM gear motors. The motor is very easily attached to the frame of the base through the use of an aluminum angle bracket at the bottom and two ¼-inch OD spacers at the top. Attachment is made using the existing motor mounting-holes. By using counter-sunk flat-head machine screws, the exterior of the mobility base is left free of protrusions and can be painted without further finishing.

The wheels, which usually come with ¼-inch shafts, are coupled to the ¼-inch motor shaft by means of a 2.5-inch long, ½-inch spacer, with an inside diameter of ¼-inch, secured to both the axle and the shaft by means of set screws. Alternatively, a .374-inch OD coupler may be used and the shaft and axle secured to it with dowel pins. Refer to Fig. 23 for details.

Two motor/wheel assemblies are used, one on each side. Front support is given by a castered wheel located at the front of the assembly. Steering is accomplished by driving only one motor, using the other as a pivot about which the robot turns. Or, for speed, one wheel may be run in one direction while the other is run in the other.

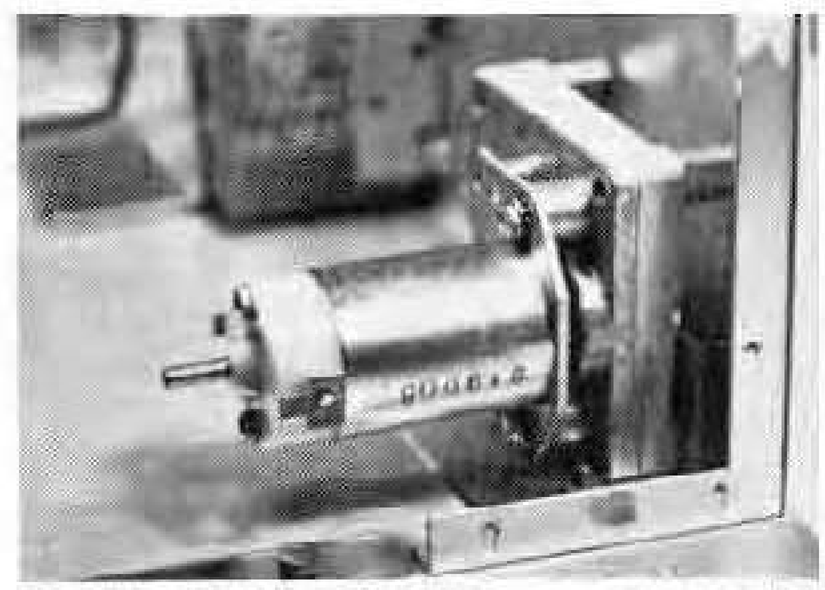


FIG. 22—ONE OF THE TWO gear motors used to drive the mobility base's wheels.

The alternate method for driving the mobility base, illustrated in Fig. 24, uses less expensive, but much faster-turning electric motors coupled to the wheels through a set of worm gears. This method, while less expensive in terms of materials, requires a lot of painstaking labor and probably the use of a well-equipped machine shop. It is presented here mostly as an exercise in developing alternate ways to achieve the same results.

The motor is mounted on a ¼-inch thick aluminum plate which, in turn, is mounted on the inside of the bottom of the mobility base using four spacers. The shaft of the motor protrudes down

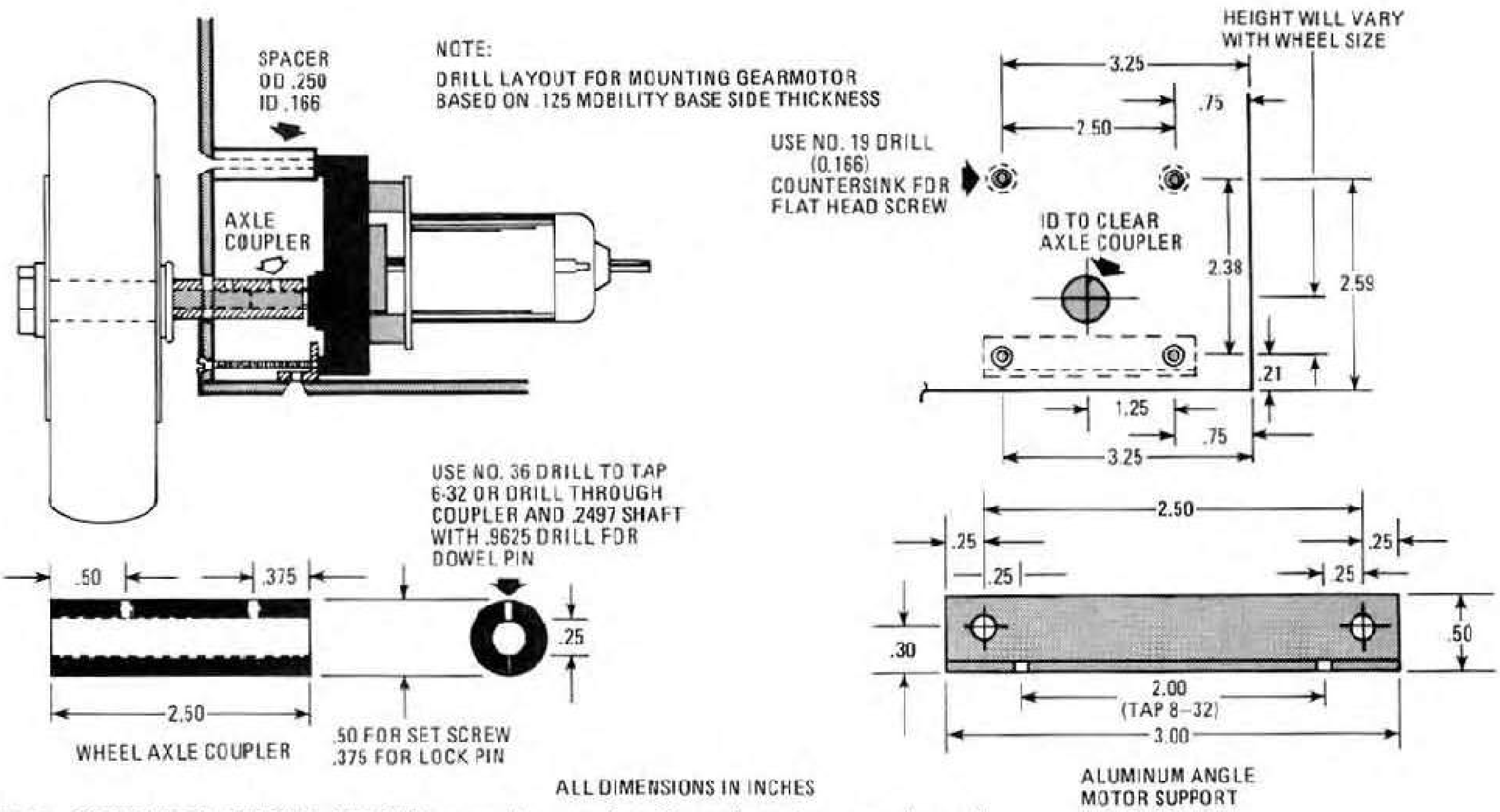


FIG. 23—MECHANICAL DETAILS of 22-RPM gear-motor mounting. Some dimensions may change if sizes of wheel or wheel-shaft you use differ from those used by author.

PARTS LIST

Item	Size	Quantity	Supplier's part no.	Supplier
Sheet metal (type 5005) aluminum	.125 x 10.5 x 19 inches	2	PA-1106 (5005 alum.)	Ⓐ, Ⓖ
	.125 x 10.5 x 15.75 inches	2	PA-1106	Ⓐ, Ⓖ
	.125 x 19.5 x 15.75 inches	1	PS-1258 (steel)	Ⓐ, Ⓖ
	.125 x 19 x 15.75 inches	1	PS-1109 (alum.)	Ⓐ, Ⓖ
(Optional—for use with motor-cycle battery and 19-inch square base)	.125 x 19 x 7 inches. Note: .0625 sheets may be used for sides if desired.	4	PA-1104 (alum.)	Ⓐ, Ⓖ
Aluminum angle	.0625 x ½ inches	16 feet	Local hardware supply store	
	or			
.125 x .75	.125 x .75 in. x 3 feet	1	BI-2901-3	Ⓐ, Ⓖ
	.125 x .75 in. x 12 feet	1	BI-2901	Ⓐ, Ⓖ
Rear panel hinge	1 x 12 inches	1	Local hardware supply store	
Worm gear	24-pitch—¼-inch bore, 30 teeth	2	W24b37-F30	Ⓐ, Ⓑ
Worm	Double pitch	2	W24s-4D	Ⓐ, Ⓑ
Wheel motors	22 RPM gear-motor	2	715-900153 (Brevel)	Ⓐ, Ⓔ
	or			
	3-amp split-phase	2	61.085	Ⓒ
Battery	lead-acid, 12-volt, 12 ampere-hours	1	local supplier	
	gelled-electrolyte, for 12 volts, 12 ampere-hours	as required	see back of **Radio-Electronics**	

SUPPLIERS:

Ⓐ **The Robot Mart**
Room. 1113
19 W. 34th St.
New York, NY 10001
($3.00 for catalog)

Ⓑ **Winfred M. Berg, Inc.**
499 Ocean Avenue
E. Rockaway, NY 11518

Ⓒ **Edmund Scientific Co.**
101 East Gloucester Pike
Barrington, NJ 08007

Ⓔ **Gledhill Electronics**
P.O. Box 1644
Marysville, CA 95901

Ⓖ **Bud Industries, Inc.**
Parts may be ordered through local electronics supplier.

NOTE: Part numbers for all items with "G" shown as supplier are those used by Bud.

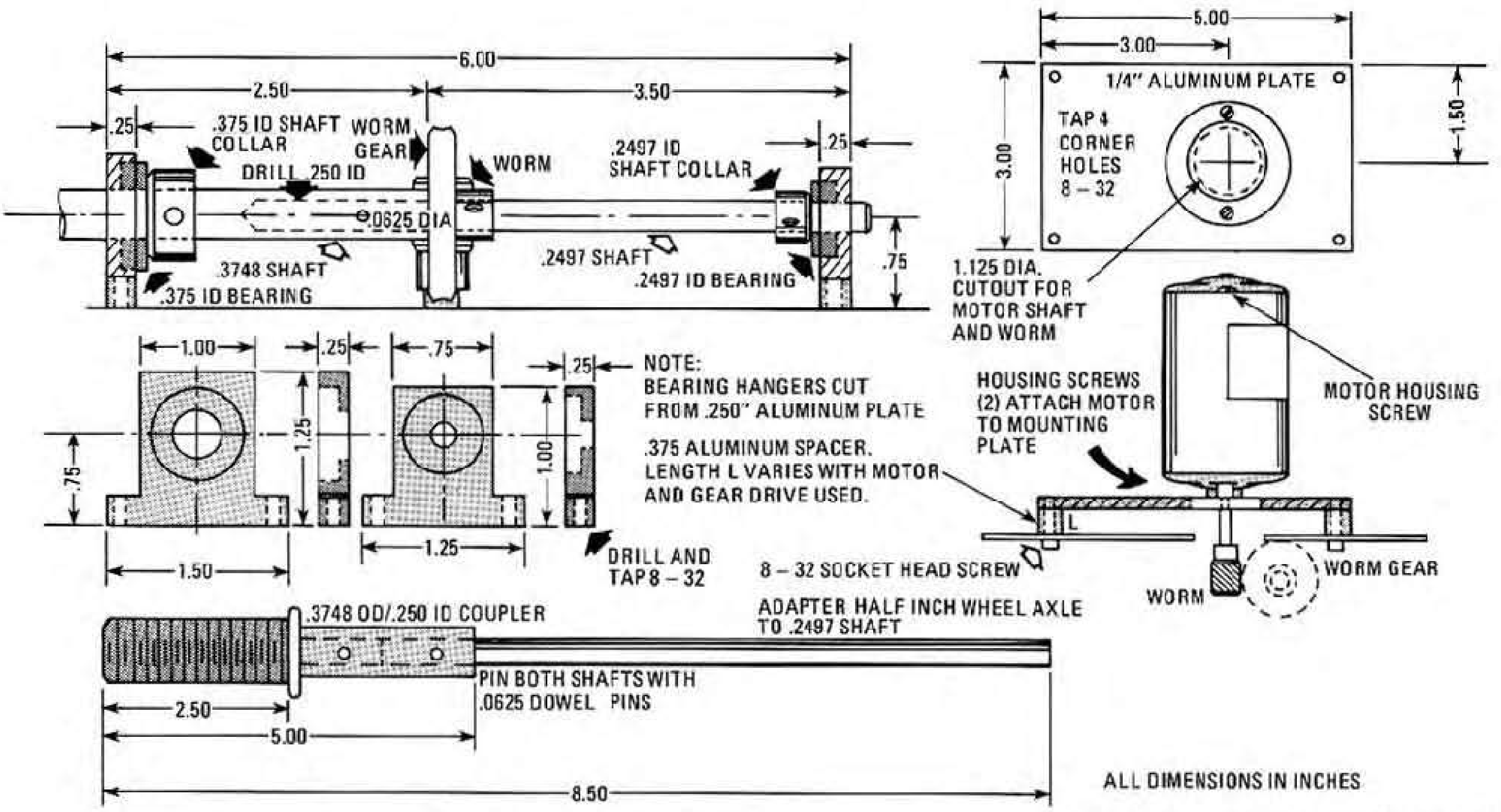


FIG. 24—MORE COMPLEX DRIVE MECHANISM is shown above. Power is transmitted to wheels through right angles, by means of worms. Gear motor drive is simpler and more reliable.

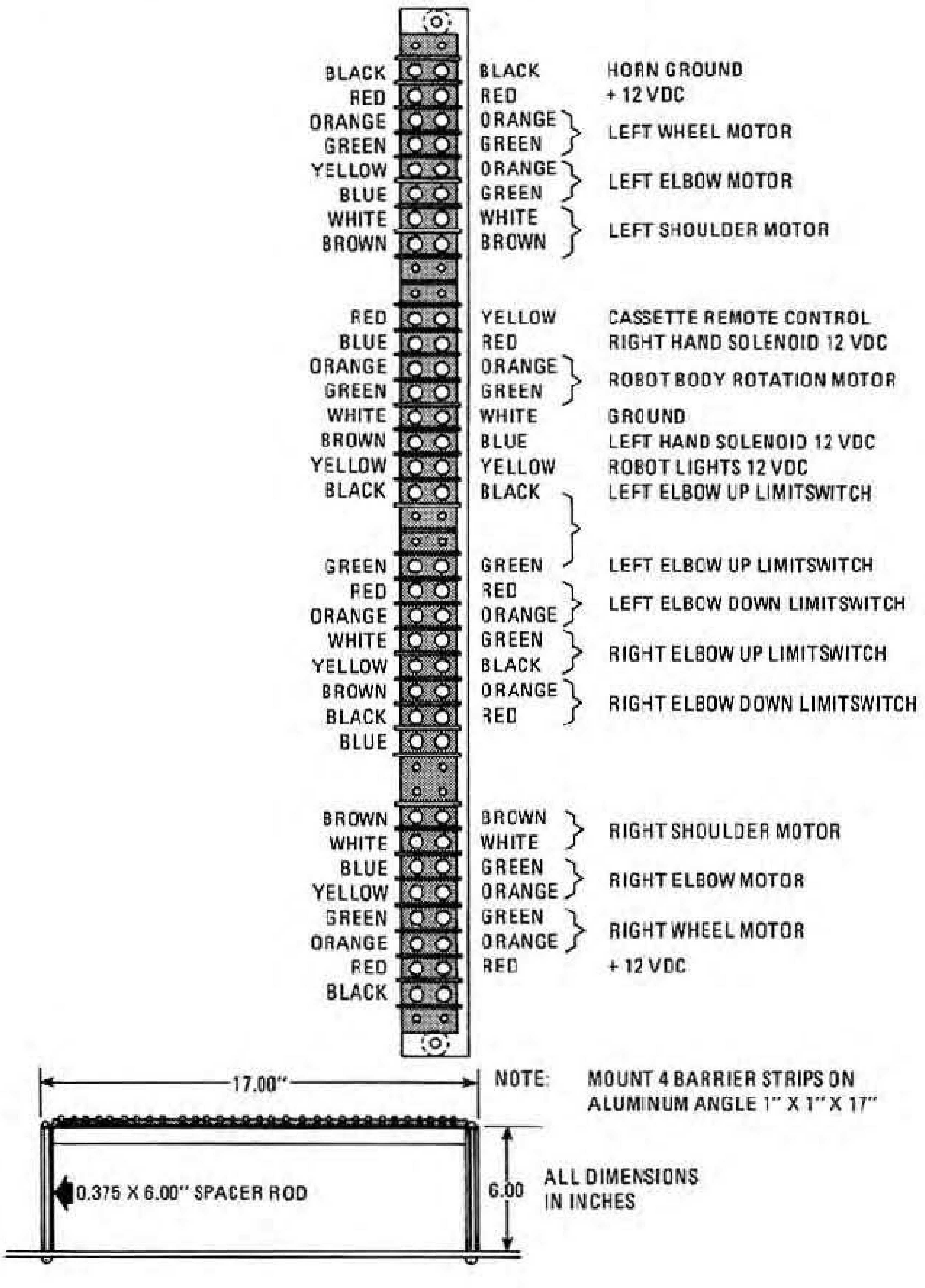


FIG. 26—THIRTY-TWO TERMINAL barrier strip (at left) for power distribution and control. Will first be connected by cable to control box and later directly to R/C receiver or computer.

through the mounting plate and through a hole in the bottom plate of the mobility base. Attached to the end of the shaft is a double pitch worm. This worm meshes with a 24-pitch, 30-tooth, worm gear, affixed to the end of the shaft which connects to the wheel. As can be seen from the diagram, several bearings are needed for this method and the bearing hangers (the plates which hold the bearings and are attached to the frame of the body) must be very carefully machined if things are to work right. Also shown in this diagram is another coupler, used to extend the length of the wheel shaft.

While this method can be made to work, it is one place where you might want to consider splurging and buying the gear motors to use in the first method presented. The extra cost will be more than offset by the ease of construction and the final result.

Power sources

Since Unicorn-One is a mobile robot, it's intended that he carry his own power source with him. He obviously can't run on flashlight batteries—in fact he needs ten to twelve amps at 12 volts. The most economical way of obtaining this power is through the use of a conventional lead-acid battery.

A motorcycle battery, mounted as shown in Fig. 25, will do the job nicely. (Note the plate to the left of the battery, which brings its leads to the outside for recharging purposes.) A frame should be

continued on page 126

UNICORN 1
continued from page 95

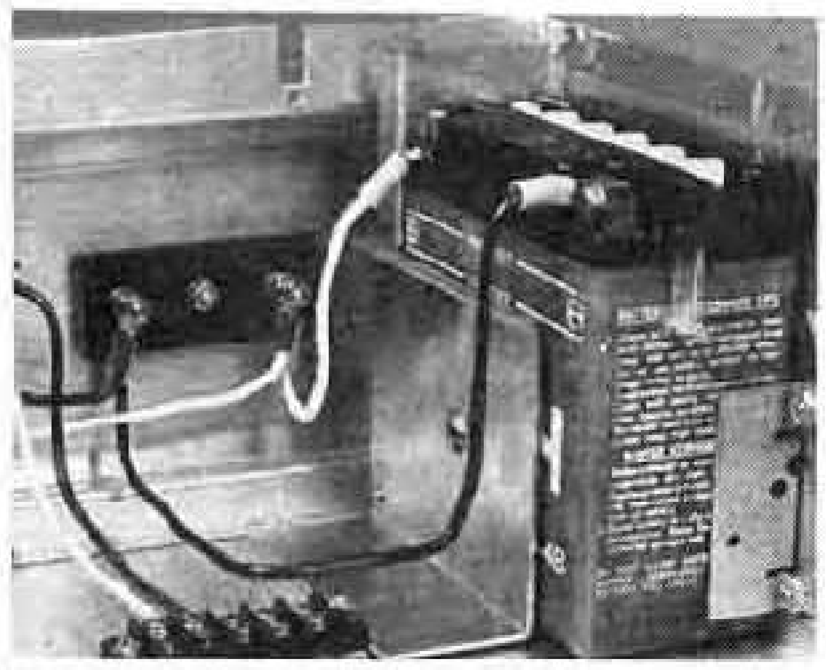


FIG. 25—MOTORCYCLE BATTERY used to power robot. See text for important mounting precautions.

used to hold the battery in place and to support its weight, since the plates that cover the mobility base are probably not strong enough to do this by themselves.

Certain precautions *must* be observed when using this type of battery! As shown in the photograph, the battery is unenclosed, which means that there exists the possibility of sulphuric acid, the battery's electrolyte, spilling on the aluminum or steel of the mobility base. You do not want this to happen! The battery should be (and is, in later versions of the robot) enclosed in an acid-proof plastic container to contain any possible leaks or drips. This container should also have a small vent, or vents, at the top to permit the hydrogen gas which is generated when the battery is charging, to escape. These vents should be led to the outside of the mobility base, to allow the gas to escape directly to the air.

There is another type of battery which might be considered for powering the robot. That uses a gelled-electrolyte and is, in theory, less hazardous. New batteries of this type are more expensive than lead-acid batteries, but several advertisers at the back of **Radio-Electronics** have surplus gelled-electrolyte available, and they may suit your purpose.

Whatever power source you use, take precautions so that it cannot harm, directly or indirectly, the innards of the robot.

Leads are run from the battery to a 32-position barrier strip (see Fig. 26) which is also mounted inside the mobility base. Power for the robot's various motors and control circuitry is obtained by running jumpers from the +12 VDC and ground terminals to those connected to the points to be powered. Note the use of color-coding in order to make circuit tracing easier.

Several terminals have been allocated for functions that have not yet been discussed. Don't worry—we'll get to them.

In the next installment of this series, plans for the robot's body will be given, along with an option or two previously hinted at. **R-E**

UNICORN-1 ROBOT

Assembling the Body

Part 4—Here's the first of two installments dealing with how to construct a body for the robot. This part describes the body frame and rotation mechanism.

JAMES A. GUPTON, JR.

SO FAR, WE'VE DISCUSSED THE DESIGN and construction of the *Unicorn-1* robot's manipulators (arms), end effectors (hands) and mobility base (legs). We are now past the most difficult aspects of its construction. This part of the series will deal with the body, and that is where the robot will begin to look like a robot.

Body frame

As shown in Fig. 27, *Unicorn-1*'s body dimensions allow plenty of interior space for whatever hardware—up to, and including, a computer—you desire to add. The prototype body is 19 inches in diameter and about 20 inches in height. That has been more than adequate for the author's needs, but does not restrict you from using other designs: after all, one of the aims of this project is to allow you to use your own ingenuity. The skin of the robot will be made of *Formica* (which comes in standard widths of 30 inches) so you will easily be able to make a body 30 inches in height, if it suits you. That is an increase of 50% in height over the original specs.

And, of course, you don't have to be restricted to the *R2D2* format. You can use just about any shape you desire.

If you haven't already done so, take an evening or two to decide what your robot will finally look like. That will not require any significant changes in the frame of the body, the principles of which we'll discuss here, but may affect you in the long run.

In any event, your robot's body will need a supporting structure, and a mechanism to turn it from side to side. That's what this section is about.

Whether the ultimate form of the body is cylindrical or otherwise, a reinforcing structure will be needed. What's shown here is for a cylindrical body, although it can easily be adapted to other shapes. Figure 28 illustrates the top and bottom bulkheads, along with the locations of the eight supporting columns. The bulkheads are made from ⅝-inch particle board, cut to dimension with a saber saw. If you have no saber saw, inscribe the circumference of the bulkheads on the board, and drill a closely-spaced series of ¼-inch holes along its *outside* as shown in Fig. 29. After those holes are drilled, the piece can be knocked out with a chisel. Whichever way you proceed, allow a bit extra for wastage—that part of the material that gets turned into sawdust or is chipped away in the process.

When the bulkheads have been rough-cut, they can be dressed to their final dimensions with a wood rasp. Who says that robots are made entirely of metal!

If you make the effort, you will probably be able to find pieces of particle board at your local lumberyard as scrap at a very reasonable price. Should you have to purchase brand-new material, you may be able to get a "special cut," if you tell the person in charge exactly what you need.

The dimensions for the interior bulkheads for *Unicorn-1* were given in Fig. 28. The top bulkhead is nothing more than a ring-shaped section of particle board, while the bottom bulkhead has a three-legged shape, to support the body during rotation. The larger bulkhead opening in that bottom part permits maximum freedom for the cables running between the body and the mobility base.

After the two bulkheads have been cut to their final shape, the locations of the bulkhead support-columns should be marked (refer again to Figs. 27 and 28). First, draw a pencilled line completely around the bulkheads' circumference. That should be done .040-inch from the perimeter. The holes drilled along that line will be used to attach the columns to the bulkhead. Figure 28 identifies the specific holes that will be required.

Some of those holes, as has been indicated, will have to be countersunk (Fig. 30). That allows the screw heads to sit flush with the outside surface, and eliminates awkward bumps or bulges when the skin is fitted.

The eight wooden bulkhead-support columns are attached to the bulkhead with wood glue or epoxy, wood screws, and aluminum angle-braces. We don't take any chances.

After drilling the bulkheads for the support columns, drill "lead holes", top and bottom, to start the wood screws. That will help prevent splitting the columns. The lead holes should be about one-third the diameter of the wood screws themselves. Then, drill *through* those holes for attachment of the aluminum braces shown in Fig. 27. Lubricate the screws with soap to permit them to

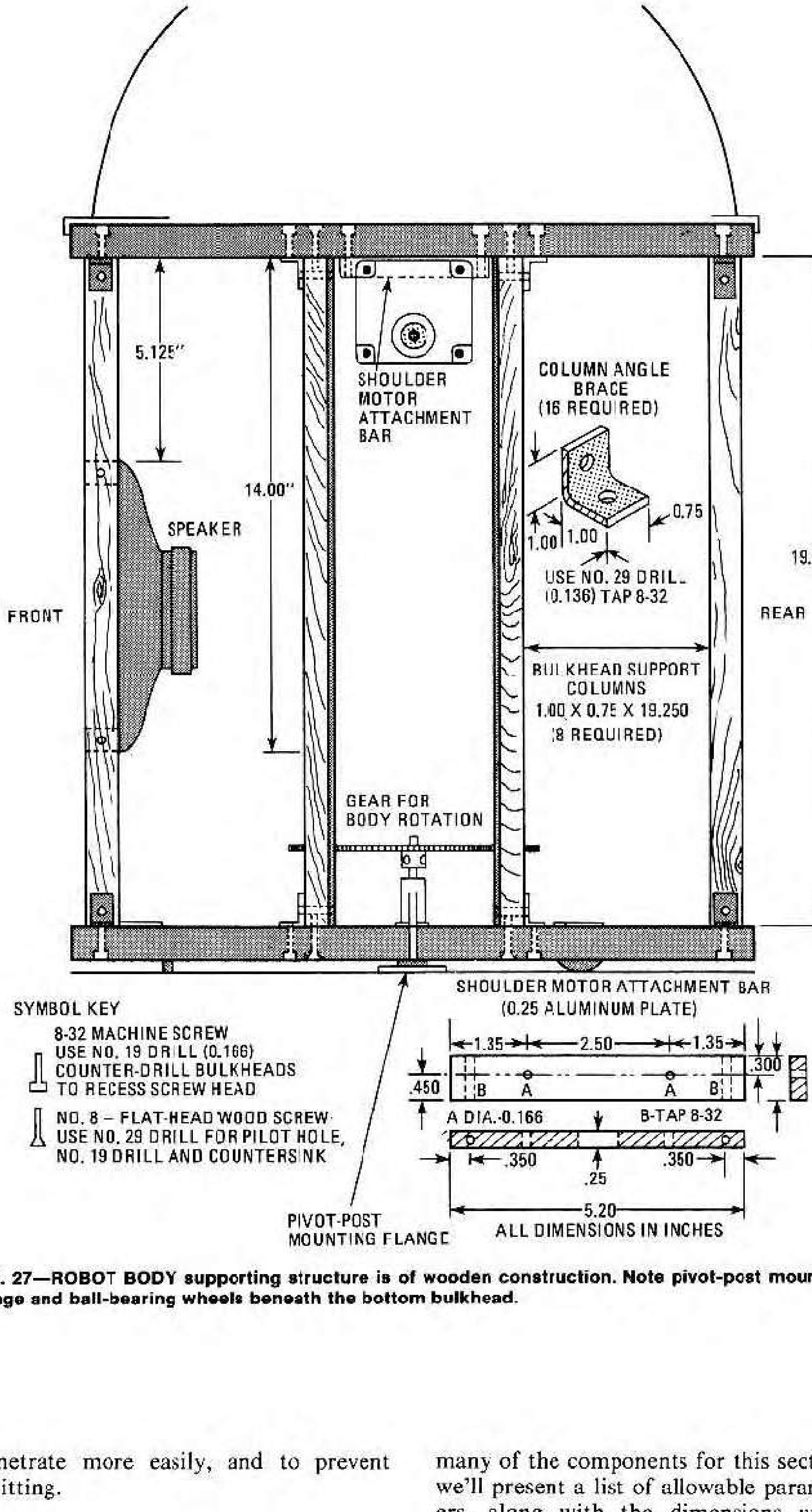
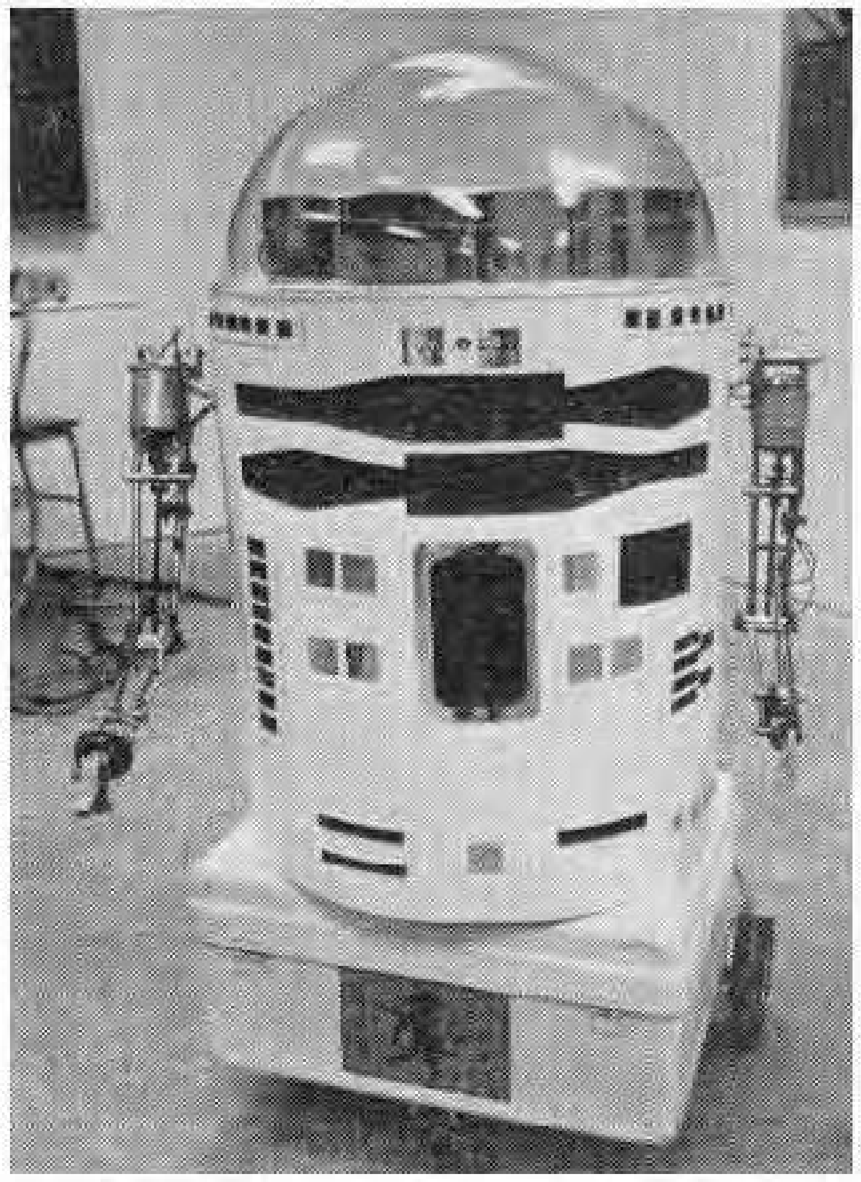
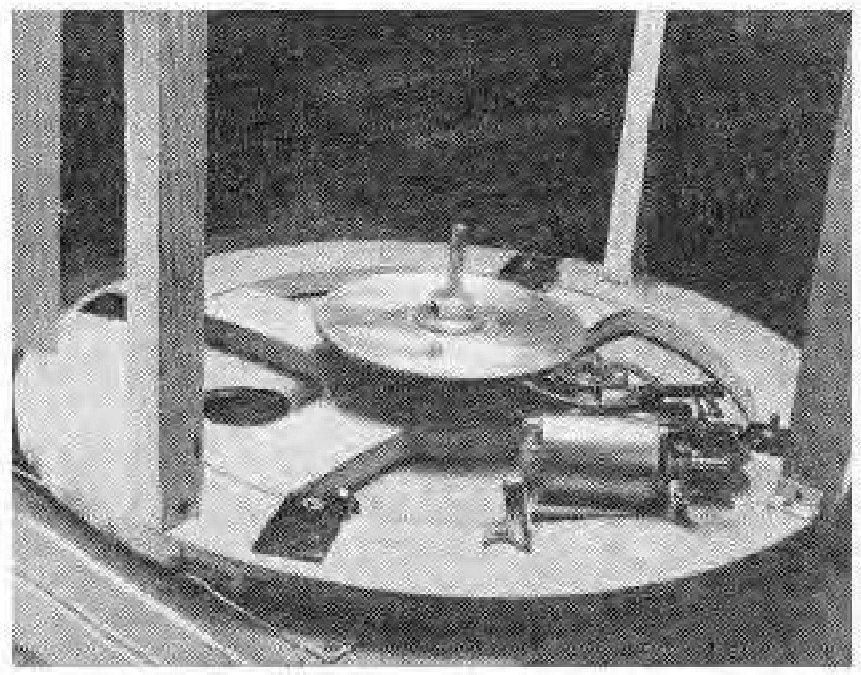


FIG. 27—ROBOT BODY supporting structure is of wooden construction. Note pivot-post mounting flange and ball-bearing wheels beneath the bottom bulkhead.



BENEATH THIS RUGGED EXTERIOR lies a frame of wood. Next installment will describe skin.



COMPLEX GEAR TRAIN used to slow 10,000-RPM motor to 11-RPM for body rotation.

penetrate more easily, and to prevent splitting.

Body rotation

Unicorn-1's body turns on ball-bearing wheels that ride on the steel plate forming the top of the mobility base. The size of those wheels is not particularly significant, as long as the body maintains its clearance from the base. The units used in the original *Unicorn-1* had a diameter of .875-inches, giving the bulkhead a clearance of .125-inch from the mobility base. One of these is shown in Fig. 31.

As we have done previously, we stress the fact that nothing about this robot is critical. Since you may be "scrounging" many of the components for this section, we'll present a list of allowable parameters, along with the dimensions we've found to be most satisfactory.

1. **Ball-bearing wheels:** .375-inch to 1.125-inches diameter. For wheels larger than .5-inch, turn the mounting plate upside down (bearing mounting-flange facing up).
2. **Pivot-post mounting flange:** .062-inch to 1-inch thick. Mount any flange thicker than .125-inch inside the top of the mobility base.
3. **Pivot-post diameter:** .250-inch to 1-inch (.250-inch to .375-inch preferred).
4. **Gear-shaft bore diameters:** .125-inch to .750-inch (.250-inch preferred).
5. **Body rotation speed:** 4 to 22 RPM (10 to 12 RPM preferred).

Just as in the design of the mobility base, there is a choice of methods to drive the body. An inexpensive, high-speed motor may be used if its speed is reduced through a series of gears. A speed-reduction of about 1000:1 is required with this method to obtain a rotational speed of 11 RPM. That, it should be obvious, requires several gears.

The amount of speed reduction is a factor of the number of teeth on each gear. If one gear has 16 teeth and another has 48, the gears have a ratio of 1:3 and driving the second gear with the first will reduce the speed by that factor (the second gear will only make one revolution for each three made by the first). A train of such gears would eventually reduce the small motor's 10,000 RPM to a useable rate, but, as Fig. 32 shows, could turn out to be somewhat complex.

Also, the speed of rotation will be affected by the weight of the load (the robot's body, in this case)—the motor speed could be slowed by 10 to 20 percent by that factor.

As in the case of using gears to drive

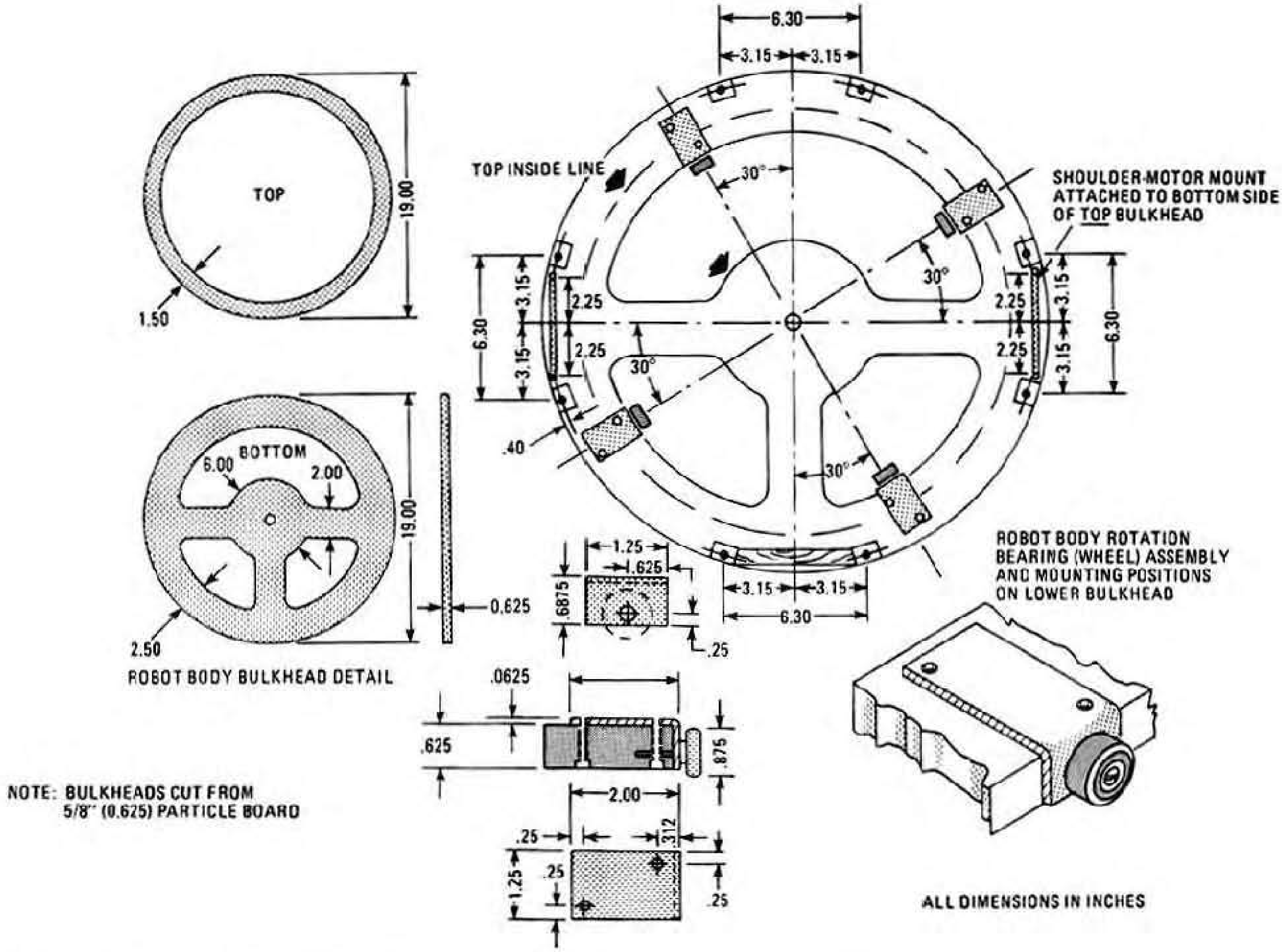


FIG. 28—**TOP AND BOTTOM BULKHEADS** are cut from particle board. Bottom bulkhead is sturdier to bear body weight. Bearing mounting brackets are made from ¼-inch aluminum.

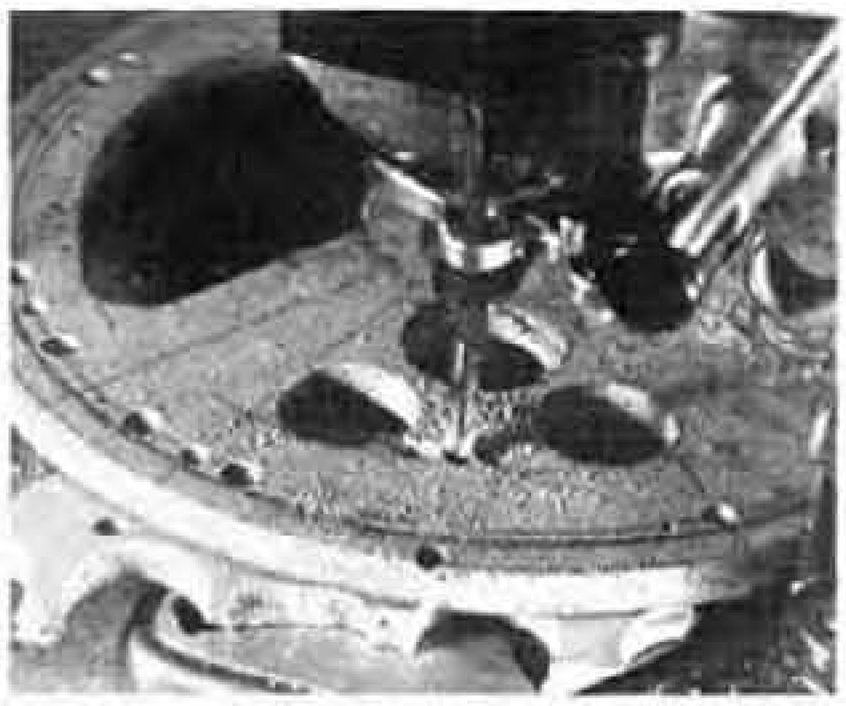


FIG. 29—**A SERIES OF SMALL HOLES** can be drilled to rough-cut bulkheads to shape.

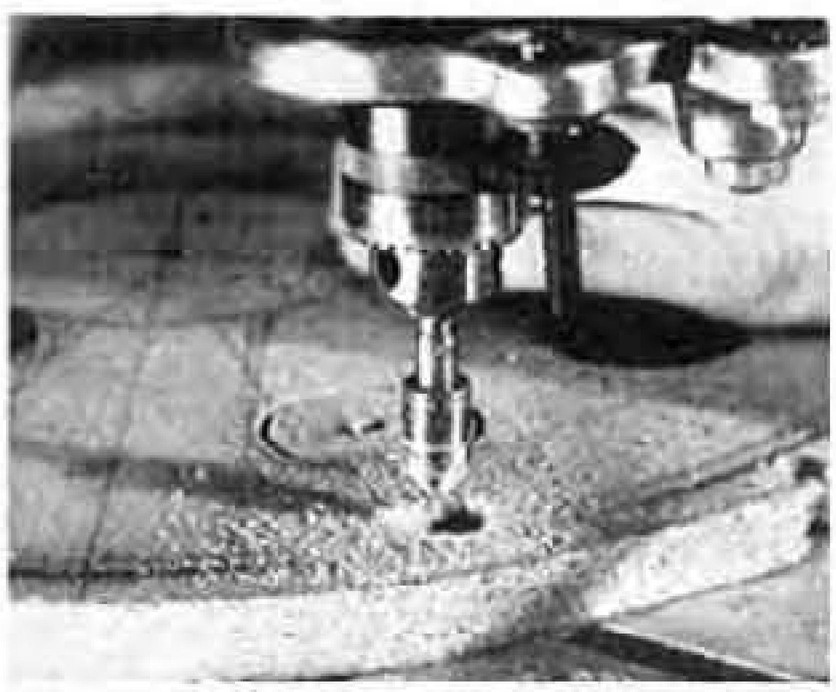


FIG. 30—**COUNTERSINKING** holes in the bulkhead prevents screwheads from protruding.

the mobility base, this method presents more problems, perhaps, than it solves.

A much simpler method uses the same type of low-speed gear motor that was used to drive the mobility base. As shown in Fig. 33, this motor can be mounted directly on the bottom bulkhead and its shaft connected directly to the pivot post and/or the pivot-post mounting flange, located on the mobility base.

Mounting of this type of motor is fairly straightforward and presents the least number of complications. A 22-RPM gearmotor may be used, or, if you can locate it, a slightly slower-speed one (about 10 or 12 RPM) may prove to be preferable.

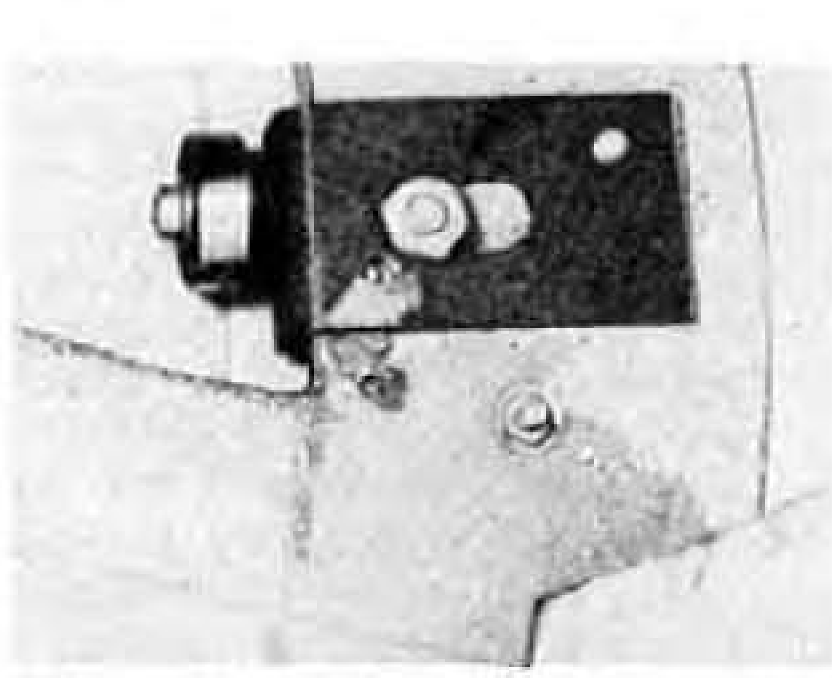


FIG. 31—**BALL-BEARING WHEELS** mounted on bottom bulkhead support body as it rotates.

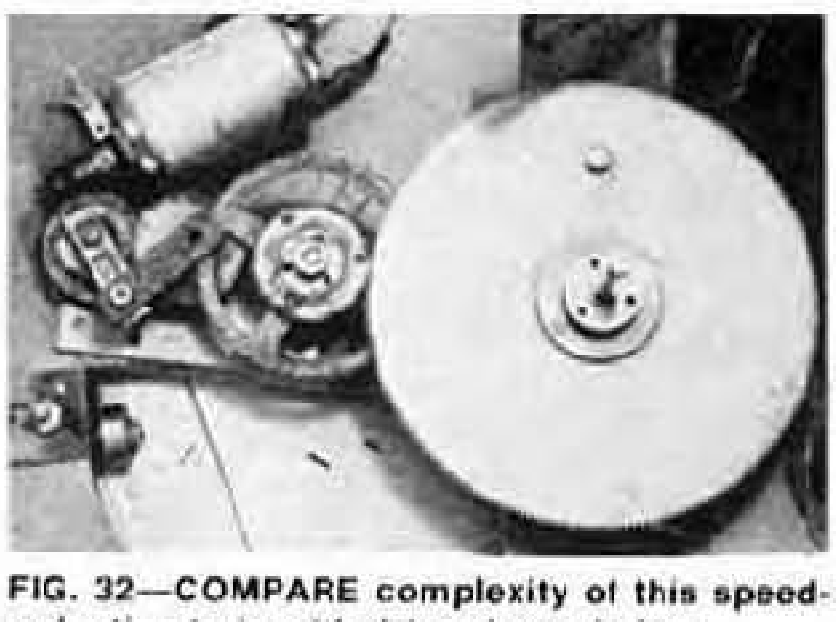


FIG. 32—**COMPARE** complexity of this speed-reduction train with drive shown below.

FIG. 33—22-RPM gear motor provides simplest and most direct means of rotating body.

Motor connection will be made to a small terminal strip mounted in the body.

Shoulder motors

When the manipulators and end effectors were described, the robot was given

PARTS LIST

Item	Size	Quantity	Supplier's part no.	Supplier
Particle board	19 × 19 in. minimum	2		Local
Wood strips	.25 × 1 × 19.25 in.	8		Local
Aluminum plate	.25 × .75 × 5.2 in.	2	AP52	(A) or local
Aluminum angle	.0625 × 1 × 1 × .75 in. (make from .0625 × 1-in. angle, 13 in. long)	16		Local
Aluminum sheet	.125 × 1.25 × 3 in.	4	AS3	(A) or local
Ball bearing wheels	.875 in. diameter, .375 in. shaft diameter	4	B11-10	(A),(B)
	or			
	.625 in. diameter, .25 in. shaft diameter	4	B11-9	(A),(B)
Wheel mounting screws (known as "shoulder screws")	To fit wheel centers	4		Local
Shoulder motor mounting screws	8-32	4		Local
Gearmotor mounting screws	8-32, length as needed	4		Local
Machine screws	8-32 × 1, Fillister-head	44		Local
Wood screws	#8 flat-head × 1 in.	20		Local
Precision spur gears (for use with high-speed motor)	48 pitch, 23 teeth, 1/8-in. face, 1/4-in. bore	3	C48A18-023	(A),(B)
	48 pitch, 120 teeth, 1/8-in. face, 1/4-in. bore	3	C48A18-120	(A), (B)
Pivot post	See text. Length to suit design	1		Local
Pivot-post mounting flange	See text	1		Local
Body motor (high-speed)	3-amp, split phase, 12 volts DC	1	61,085	(C)
	or			
Body motor (22-RPM gearmotor)	22-RPM gearmotor, 12 volts DC	1	715-900153	(A), (D)
Shoulder motor	22-RPM gearmotor, 12 volts DC	2	715-900153	(A), (D)

SUPPLIERS

(A) **The Robot Mart**
Room 1113
19 W. 34th St.
New York, NY 10001
(Catalog $3.00)

(B) **Winfred M. Berg, Inc.**
499 Ocean Avenue
E. Rockaway, NY 11518

(C) **Edmund Scientific Co.**
101 East Gloucester Pike
Barrington, NJ 08007

(D) **Gledhill Electronics**
P.O. Box 1644
Marysville, CA 95901

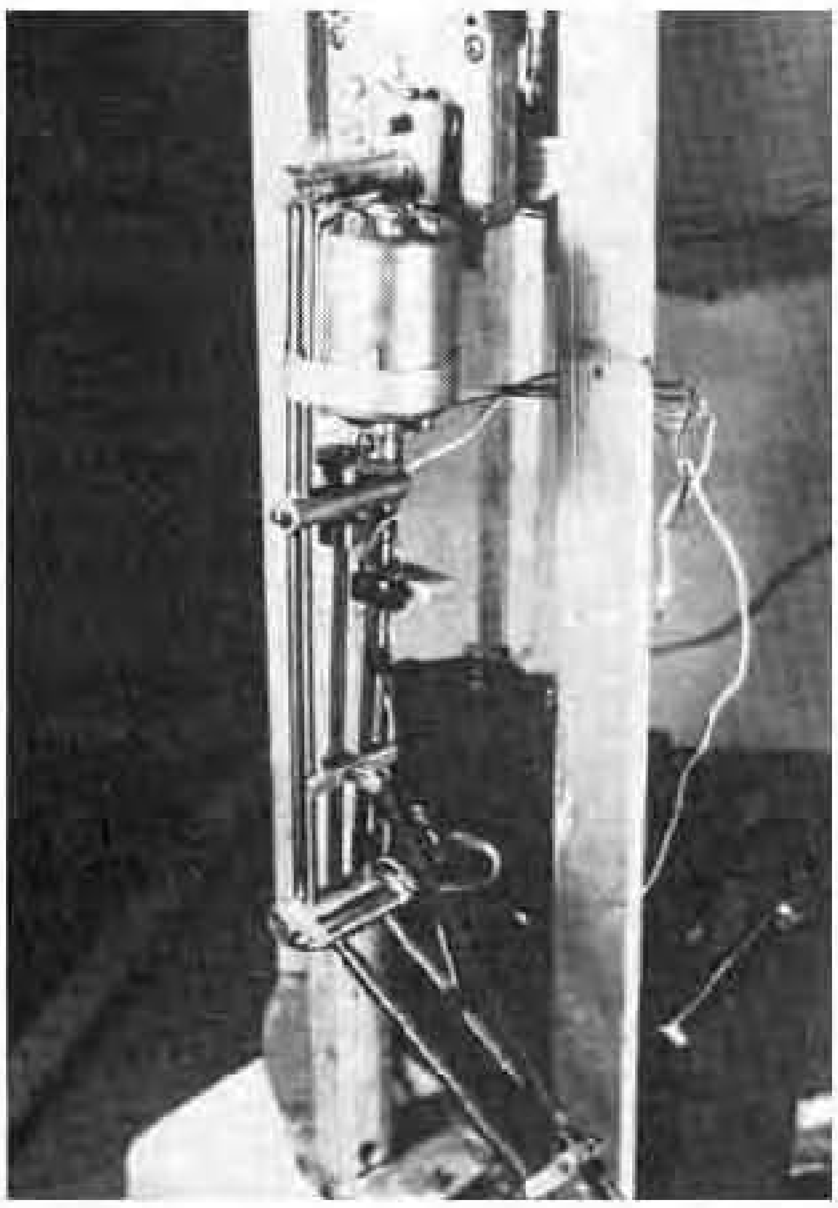


FIG. 34—SHOULDER MOTOR mounting plate is visible at very top of photograph. See Fig. 27 for body location.

the ability to bend his arms at the elbow and to open and close his hands. It would be useful to add another degree of freedom, which would allow the arms to be raised and lowered. That is easily accomplished with the same 22-RPM gearmotors we've already used.

A five-ohm, 20-watt resistor can be used to drop the motor's supply-voltage, thus slowing it down to a more suitable speed. (The same can be done for the body motor.)

The last cross-bar rod (at the shoulder hinge) on the manipulators has already been drilled to accept a shaft of the type found on these motors (refer back to Part 1, August 1980 issue). A simple bracket, shown in Fig. 27, allows the motor to be attached to the body. An actual installation of that sort is pictured in Fig. 34. Be sure that the mount is positioned so the surface of the gearmotor will be flush with the surface of the top bulkhead since, when the robot's skin is attached, a cutout will have to be made for the shoulder gearmotors, and their faces should be flush with the skin's surface.

Again, the shoulder-motor wiring will be connected to a local terminal strip.

Alternatively, the manipulators may be affixed to .250-inch rods that are attached to the body frame, without motors. The motors can always be added later.

Bear in mind that, although the skin will be removable, as much interior work as possible should be completed before it is attached. Some of the things that remain to be added are:

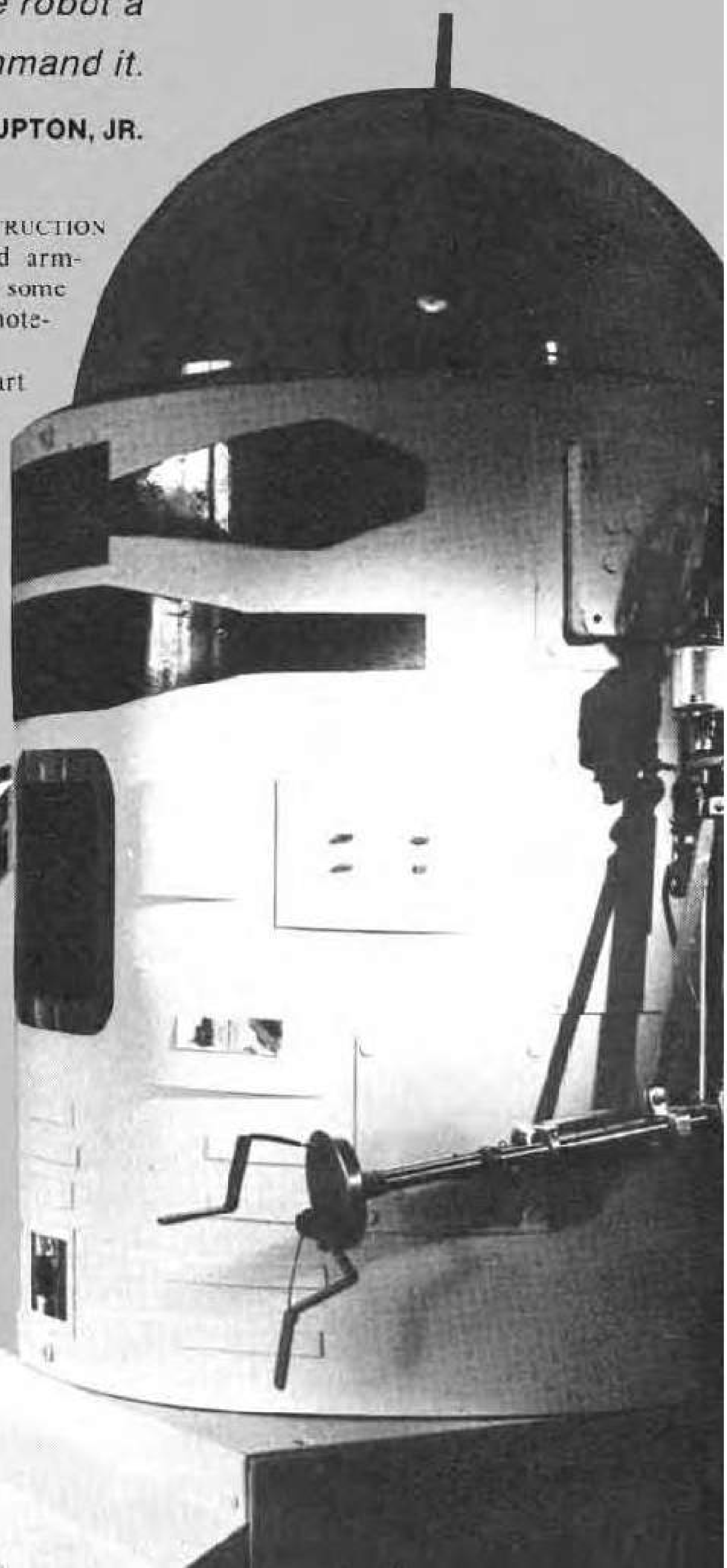
1. "Local" terminal strips for motor wiring and connections from them to the master terminal strip in the mobility base.
2. Speaker and LED installation.
3. Installation of supports and brackets for radio control and/or computer equipment.

In the next section of this series, we'll complete the work described above and attach the skin. In addition, we'll describe the construction of the control box that will allow you to operate the robot by means of a cable running to the mobility base. **R-E**

UNICORN-1 ROBOT

Part 5—It's time to get the show on the road! In this part we'll finish the body, give the robot a voice, and provide the means to command it.

JAMES A. GUPTON, JR.



LAST MONTH, THE FOURTH PART OF THIS SERIES DESCRIBED THE CONSTRUCTION of the body frame and covered the areas of adding body rotation and arm-movement capabilities. In this part we'll complete the body wiring, add some simple electronics, cover the frame with a decorative skin, and build a remote-control box.

Before getting started, a point about the shoulder motors, discussed in Part 4, must be made. The gear motors recommended usually have their drive-shafts offset slightly from the center. That means that if both the left and the right motors were to be installed right-side-up, one arm would be farther forward than the other.

To avoid that embarrassment, mount one of the motors upside down.

Figure 35 illustrates the use of terminal strips for motor connections and limit-switch wiring. Those "local" terminal strips simplify connections between the components and the 32-position "master" terminal strip located in the mobility base. Circuit tracing is further simplified by the use of separate cables for the right and left sides of the robot's body. Color coding is used extensively to make things even easier to follow. But even if you use the wiring diagrams provided with this series it would be a good idea for you to make your own diagrams, showing the color codes and terminal identification system you use. That will fix in your mind exactly how *your* robot is set up.

A "left" terminal strip and a "right" one should be attached to the same support columns used to mount the shoulder motors. If shoulder motors are still in the future for your robot, the strips can be mounted on the columns nearest the points where the arms are attached to the body.

Voice of the robot

Two inexpensive options you can add to your robot are an amplifier and speaker, and a horn. The speaker is located at the front of the robot, between two support columns (that is shown in Fig. 27 of Part 4). Two crosspieces should be added to give the speaker further support. Figure 36 shows a 6 × 9-inch speaker, together with a 12-volt horn, in place. Take care to "contour" the

FIG. 35—LOCAL TERMINAL STRIPS make connections to motors and switches simpler.

FIG. 36—SPEAKER AND HORN will later be covered by grille mounted over hole in skin.

crosspieces to conform to the bulkhead shapes, in order to prevent the skin from bulging at this location.

The amplifier for the speaker can be new, or scrounged (from a discarded 8-track tape player, for example), or built from scratch using one or two IC's. If you decide to build your own, refer to back issues of **Radio-Electronics** for ideas. For example, see "μA783 Audio Amplifier," November 1980 issue.

The voice of the robot may be prerecorded on cassette and played back through an inexpensive recorder, using the amplifier and speaker connected to the recorder's earphone jack. The cassette recorder's motor can be controlled from the command console through a connection to the recorder's MOTOR jack by means of a subminiature phone plug.

It would be a good idea to use miniature phone jacks at the amplifier so that the speaker and audio connections can be easily disconnected if repairs are needed, and to simplify the changeover from cassette recorder to wireless microphone later on.

The skin

So far, the robot has taken shape pretty well, but has still looked somewhat . . . naked. Now that the terminal strips and audio options have been installed, we can remedy that.

The fabrication of the skin is a bit tricky, so take your time, have patience, and double-check each step before going on to the next. Your efforts will be rewarded in the end.

The skin will be made out of *Formica*, which is available in 30-inch widths at most lumber or construction-supply houses. For the size robot we've been describing, you'll need 65 inches of .030-inch thick material. Figure 37 shows the final skin dimensions.

The first, and most difficult, part of this operation involves cutting the holes for the shoulder motors so that everything will line up perfectly. You'd better get someone to help you.

To start, use a *metal* tape measure (the fabric ones used in making clothes are not accurate enough) to determine the distance along the circumference of the top bulkhead from the front edge of one shoulder-motor housing to the front edge of the other. Mark the top bulkhead at the midway point.

The tape measure has to be held firmly against the bulkhead all the way, and must not sag. Also, to avoid any error that might be induced by the presence of the end-clip (it will prevent you from keeping the end of the tape measure in contact with the bulkhead), start measuring three or four inches from the end of the tape.

Remember, later, that you did this! If you started three inches from the end of the tape, and your reading was 22 inches, the *actual* distance was 19 inches!

Now, unroll the sheet of skin material with its slick side (that will become the outside of the skin) up. Using one-inch-wide masking tape, secure it to a flat surface and measure it from end to end, the long way, to determine its center. Do that near both the "top" and the "bottom" of the sheet and then draw a center line through both points, using a china-marking pencil.

On either side of the center line, mark the positions of the shoulder-motor front edges. Do that by first dividing the distance measured earlier along the top bulkhead by two, and then making a mark, on either side of the center line, at this distance from it.

Then measure the horizontal and vertical dimensions of the shoulder-motor faceplates, and note their distance from the top of the top bulkhead. Mark those points on the skin material, using the front-edge markings as a starting point. You should wind up with a rectangle *approximately* the size of the motor-mounting plates and starting about ¼-inch from the top of the material, if you are building a robot the same size as the prototype.

Before you start on the shoulder motor openings, double-check all your measurements! Remember, you're a surgeon, now. With an old magazine or pile of newspapers under the work area, you can begin. You can use either a single-edged razor blade (dangerous), a sharp pocket knife (also dangerous), or an *X-acto* knife (less dangerous). Work gloves wouldn't be a bad idea.

Very carefully, cut along the *inside* of the inscribed area, using several light strokes rather than one heavy one. The

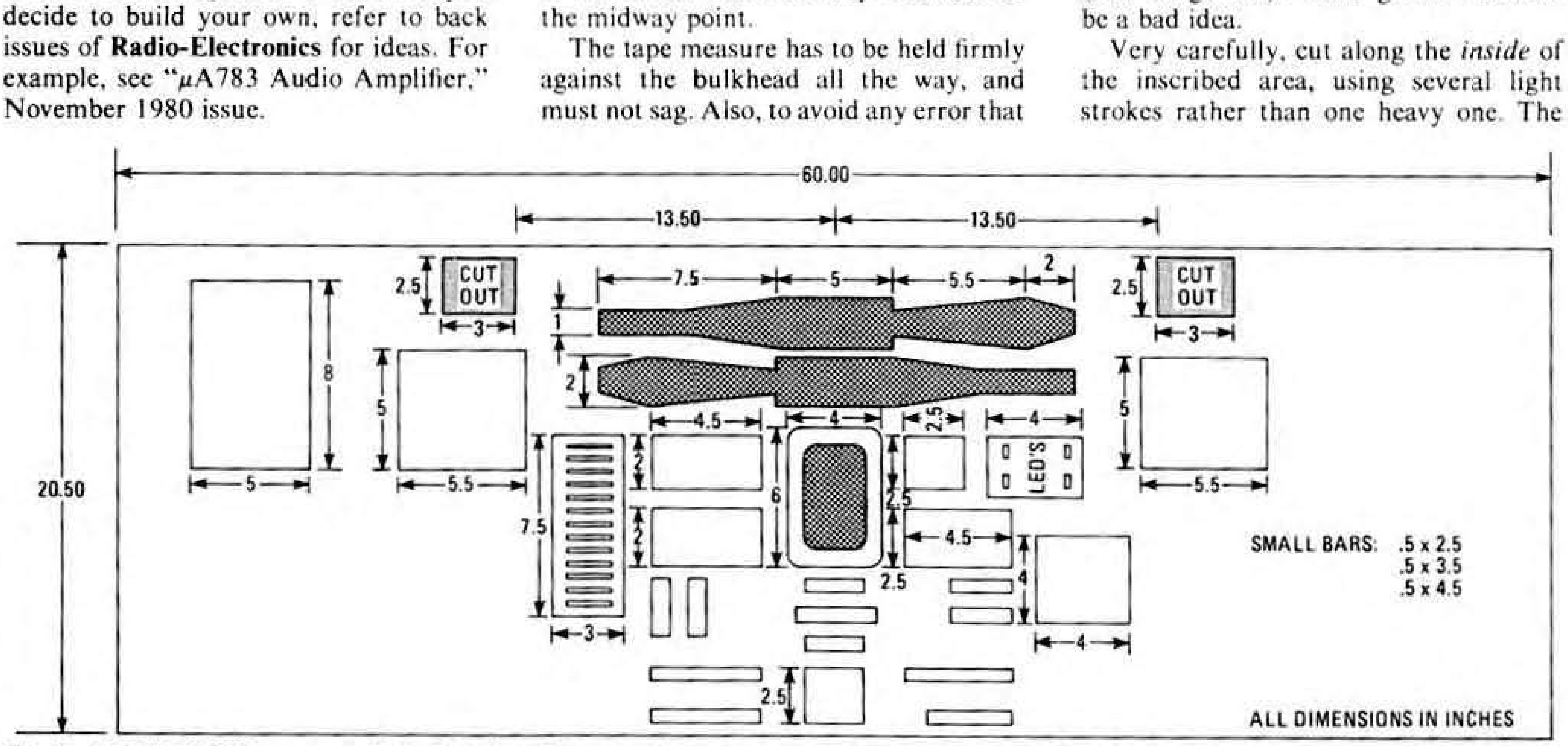


FIG. 37—FORMICA SKIN measures 20.5 x 60 inches. Text gives information on skin embellishments.

PARTS LIST

Item	Size	Quantity	Supplier's part no.	Supplier
Formica	30 × 60 in., .030-in. thick	1		Local
Plastic dome	18-in. diameter	1	85,216	Ⓒ
	or 12-in. diameter	1	85,108	Ⓒ
Grommets	to fit ½-in. hole	4		Local
Self-tapping screws	½-inch	5 (see text)		Local
Spray paint	13-oz. can	3		Local
Speaker	6 × 9 inches	1	40-1268	Ⓘ
Buzzer	12 VDC	1	273-051	Ⓘ
Cable	8-conductor color coded	100 ft.		Ⓙ
	or 15-conductor color-coded	50 ft.		
Control box	7 × 11 × 2 inches (approx.)			Ⓙ

Item	Size	Quantity	Supplier's part no.	Supplier
Terminal strip	8-position	3	264-670	Ⓘ
Switches: S1, 57	SPST	2	275-324	Ⓘ
S2, S5, S9	N.O. momentary pushbutton	3	275-1547	Ⓘ
S3, S4, S6, S8, S10-S12	DPDT, center-off	7	275-1545	Ⓘ

Miscellaneous: amplifier and cassette recorder, decorative trim, adhesive, hardware for speaker and horn mounting, etc.

SUPPLIERS:

Ⓒ **Edmund Scientific Co.**
101 East Gloucester Pike
Barrington, NJ 08007

Ⓘ **Radio Shack**
(consult local phone book)

Ⓙ **Electronics supply house**
(consult local phone book)

first cut should do no more than leave a slight mark on the surface; if you apply too great a pressure on the material, you can fracture it. That is critical along the top edge of the motor opening, since it can weaken the skin in this area, and could cause it to split later on.

If you do make an error, though—either in location or in "surgery"—you get one more chance. The material is wide enough for you to rotate it 180 degrees and start again. That, however, is your last chance! (Actually, you get one more—you can bury your mistakes under a "gasket" made of ½-inch strips of skin material cemented around the openings like a picture frame.)

After both openings have been cut, press the skin against the body to verify their positioning—but don't expect an exact fit at this point. You will almost certainly have to file the openings to size. Gently use a fine warding file to enlarge

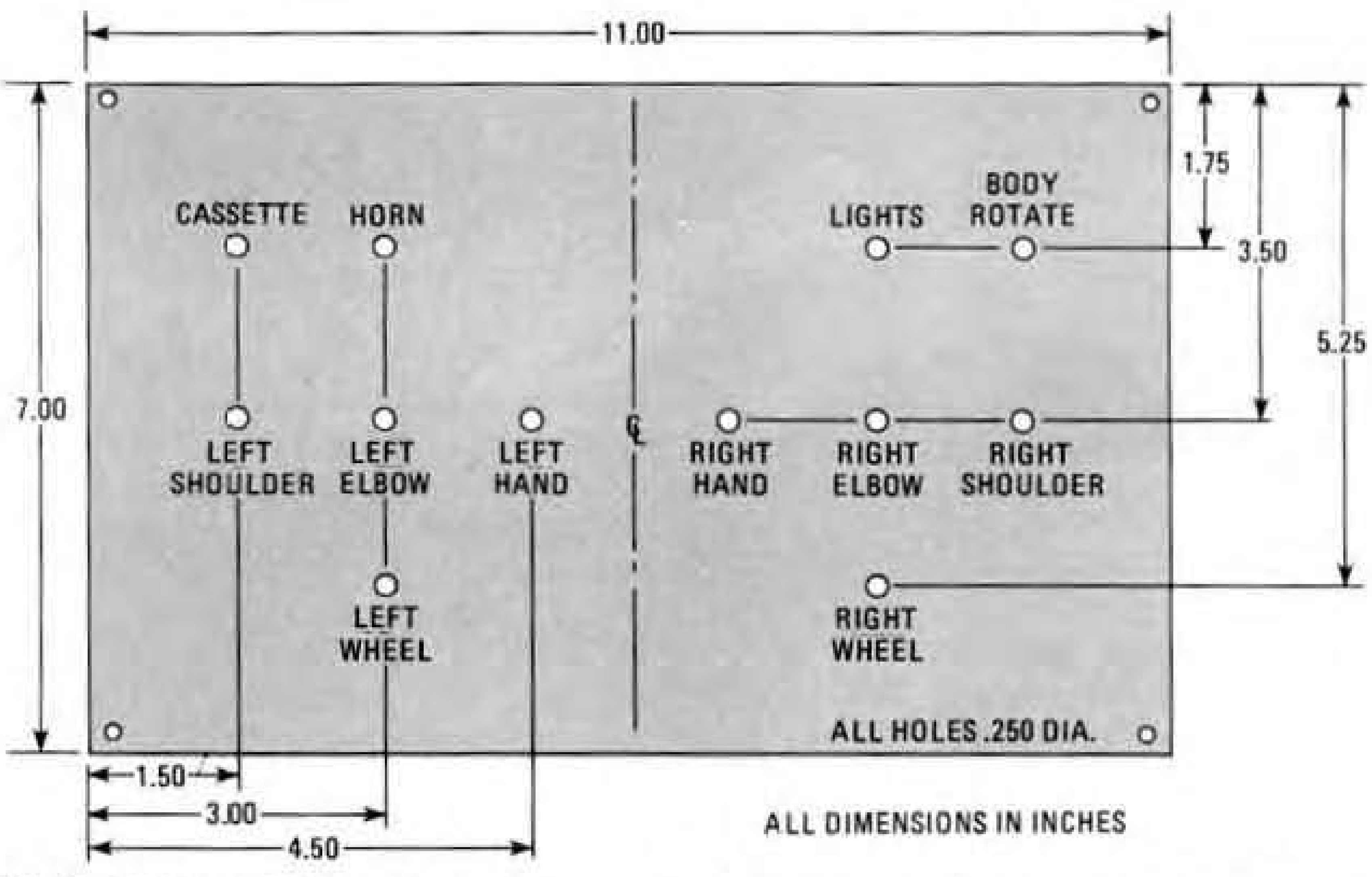


FIG. 39—DRILLING TEMPLATE shows suggested switch placement. Dimensions and layout may be revised to meet specific requirements.

FIG. 38—COMMAND CONSOLE provides the means for controlling remotely via cable.

the holes. **Always file from the outside in, using single strokes. Never apply pressure on the return stroke, since that will cause the surface of the skin material to chip.**

When the motor-mount openings have been trued and fitted, the next step is to measure the distance from the top of the top bulkhead to the bottom of the bottom one. Transfer that dimension to the skin material (in at least two places) and draw a line along the entire length of the skin to indicate its bottom. Cut along the outside of that line using a pair of heavy scissors. You should now have a piece of material that will completely enclose the robot's body—and then some. Save the part you cut off—it can be turned into surface embossments later.

Place the skin into position over the robot's body, using the shoulder-motor openings as locating points. Wrap the skin around the body so it overlaps. Locate the nearest support-column position and mark the skin on both sides of it to give at least ½-inch of overlap at that point. Be sure to mark both the top and bottom of the skin. You can use the scissors to cut the skin to size.

One more opening has to be cut—the one for the speaker. Remove the skin from the robot and again tape it down in your work area. Determine where the speaker opening will be (use the same techniques described above) and mark a rectangle over the center line that is ½-inch smaller on each side than the size of the speaker cone. The surgical technique for cutting this hole is the same as before.

Embellishments

There are several simple things that can be done to give the robot a more sophisticated appearance. The easiest is to cover the speaker opening with a piece of porous foamed-plastic or metal speaker-grille material. That, of course, should be mounted from the inside of the skin.

Self-adhesive, metallized sheet plastic can be used to give the effect of chrome.

The skin may be embossed using remnants of the skin material, cut to size and attached with contact cement, plastic glue or epoxy. The smooth surface of the skin material is reluctant to accept certain cements and should be roughened with coarse sandpaper prior to receiving the add-on's. Use weights on the embossments until the glue sets. You can get some ideas for embossments from those shown in Fig. 37, but let your imagination rein free!

In cutting out the embossments, you should observe the natural curve of the material. The shapes you cut for *horizontal* embossments should be cut so their grain runs the same way as that of the skin. Those for *vertical* shapes should be cut against the natural curl.

An ordinary hole-punch can be used to simulate rivets or—better yet—screw heads can be severed from their stems and glued to the skin. Try using silicone sealing compound, which will give adhesion along with a bit of flexibility.

Once the cement has set, the skin can be permanently affixed to the body. After seating the motor facings in their openings, wrap the skin around the body to the "lap" position you determined earlier. Start at the center line and drill a small hole to, and through, the top bulkhead to act as the lead hole for a sheet-metal self-tapping screw.

That type of screw is preferred because it holds better in particle board (the bulkhead material) than regular wood screws.

If your alignment is good, you'll need only five screws to secure the skin—one each at the top and bottom of the front center-line, and one each at the top, middle and bottom of the rear overlap area. Use more if it makes you feel better.

Finishing

Before you paint the body, clean it up. Excess cement that may have seeped from under the embossments can be removed using a sharp blade. If there is so much seepage that it resists cutting, remove it with a file and, toward the end,

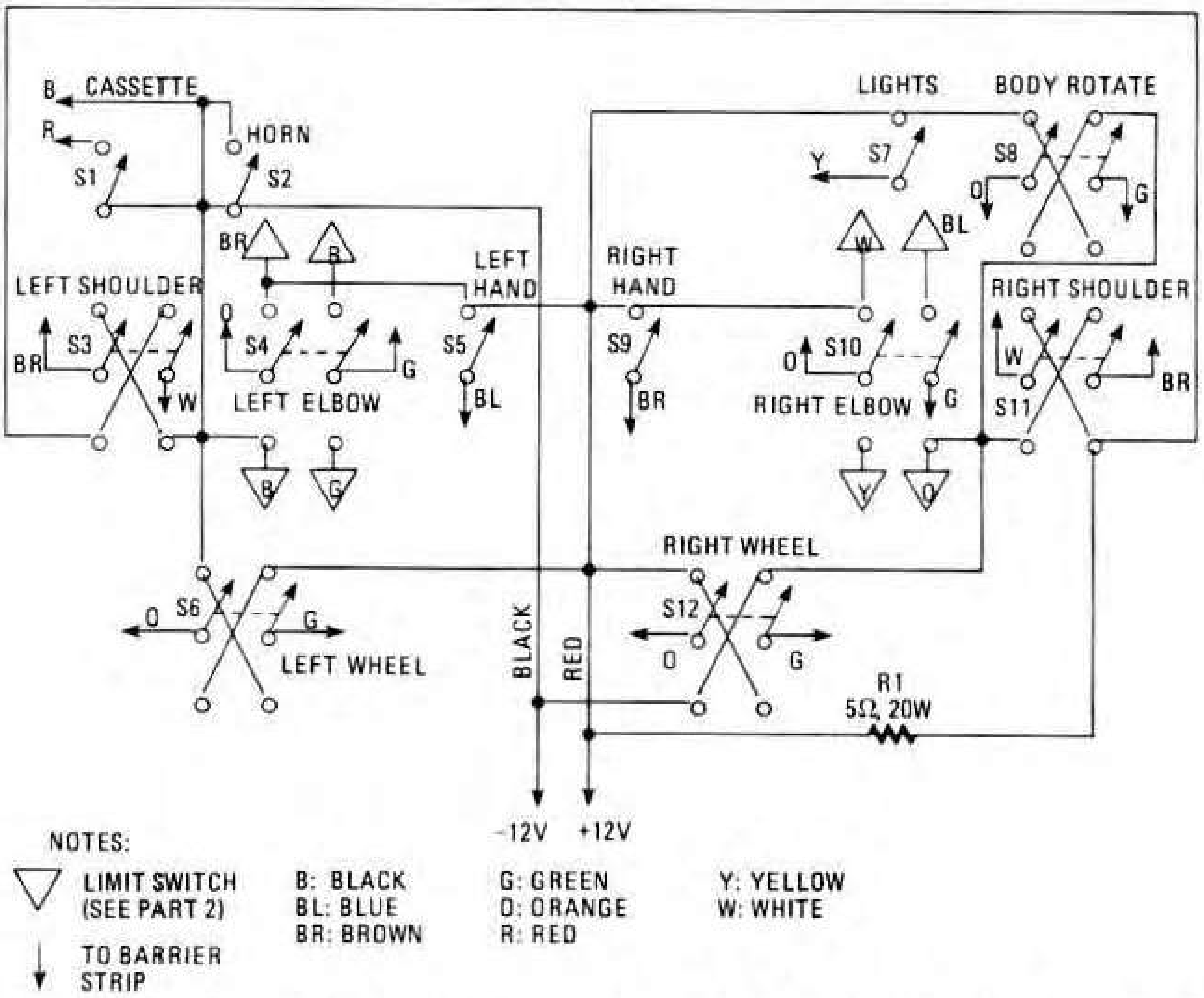


FIG. 40—CONTROL CONSOLE wiring diagram, as viewed from *top* of switch panel. Switches are shown in black; wiring and connections to terminals in color.

with No. 000 emery cloth.

Before applying the paint, cover any metallized areas with masking tape, trimmed to size. Also, be sure to cover the speaker opening. You don't have to cover the motor-mounting plate or the motor shaft unless the shaft already fits very tightly into the *manipulator's* opening. If that is the case, tape only the shaft.

Also, cover any areas—such as the mobility base—that you may not want to paint, or may want to paint a different color. (If necessary, a little paint remover, *gingerly applied*, will completely erase your mistakes.)

Flat white (although the choice is up to you) spray enamel produces a good finish, and three light coats will do a better job than one heavy one. Hold the spray can about a foot from the surface, using strokes that begin at the top of the body and go to the bottom. Work your way around the body, and then rest and let the paint dry. Do that three times.

If, for some reason, the paint drips, let it dry completely and then file and sand it down. Repaint that area very lightly. (Such repainting *doesn't* count as one of the three coats.)

Any embossments you want to be of a color different from that of the skin should be painted before the skin is done. After the skin has been painted, the appropriate areas should be roughened and the embossments cemented to them. Take care—touching up can be very touchy!

Finallly, before attaching the robot's manipulators to the shoulder motors, drill or punch (using a chassis punch) two ½-inch diameter holes, about one inch apart, in the skin on either side of the gear-motor axle, and about two inches below it. Place rubber grommets into those holes to protect the motor and limit-switch wires that you will now pass through them—to be connected to the "local" terminal strips—from abrasion. Allow enough slack in those wires to permit the manipulators to move from a straight-up position to one about 45 degrees beyond the straight-down one (so they extend slightly behind the robot).

Control console

This is the moment we've been waiting for—the means to give the robot its first instructions. The control console, shown

FIG. 41—ROBOT'S DOME can be made from salad-spinner or from terrarium cover.

in Figs. 38 and 39, is connected by an umbilical cable to the mobility base. The box may be any convenient size—the author used one measuring 7 × 11 × 2 inches. The switch holes are ¼-inch in diameter and should be drilled before the control console is finished. Refer to Fig. 40 for a top view of the console, showing the wiring connections. Note the use of color-coding. A total of 12 switches is required (see parts list). Press-on lettering can be used to designate the switch functions, and a coat of clear acrylic spray applied to protect the labels from wear and tear.

The umbilical cable may be made up of four 8-wire cables, or two 15-wire ones. It will run to the 32-position mobility base terminal strip (Part 3, Fig. 26), from which signals will be routed to the appropriate switches and motors. While DC power *can* be supplied to the robot via the umbilical cable, heavy cable would be needed; it is better to rely on the battery in the mobility base (see Part 3).

It should be noted that the 12-volt negative (−) line is common to all switches, including those wired to operate at reduced voltage (with 5-ohm dropping resistors).

The reader should also refer to Part 2 of this series, which discusses the wiring of the limit switches—and give particular attention to Fig. 18.

Finally, the robot's crowning glory, shown being added in Fig. 41, is a clear plastic dome—that can be made from part of a "salad-spinner" or is available from the source indicated in the parts lists.

This completes the basic design details of Unicorn-1 . . . but there's more to come. The next installment will cover such topics as:

1. LED's for motor-direction indication.
2. A rotatable end effector for the robot's arm and a new extendible arm.

And those two items are only the beginning . . . **R-E**

Solid State News

HMOS 2114 RAM

Intel has announced the 2114A HMOS version of the 1K × 4-bit static random-access-memory. While it draws 40% less current than the standard 2114 part, the new version has a speed range of 120 to 250 nanoseconds. Pin-for-pin compatibility between the old and new parts make them useful in upgrading existing systems as well as in new designs of microprocessor systems, buffer memories, and main memory systems.

Intel has now had three years experience with the HMOS process and says that it has proven to be very reliable and widely accepted.

The RAM's range from the 120 nanosecond, 40 milliamp, 2114-AL-2 to the 250 nanosecond, 70 milliamp, 2114A-5. Prices for the respective RAM's are $20 each for the high-speed, low-current IC, and $10.80 each for the higher-current, lower-speed part, in 100 quantities.

Intel is also offering a math processor IC to add high-speed mathematical capability to microprocessor systems. Most microcomputers rely on software routines to carry out time-consuming math functions. The Intel 8232 and 8231 arithmetic-processing units are aimed at industrial control, numerical control, scientific calculation, and graphics and pattern generation. Speed improvements are in the range of 10 to 100 times compared to software-supported floating-point math systems. The IC's referred to are shown in in Fig. 1.

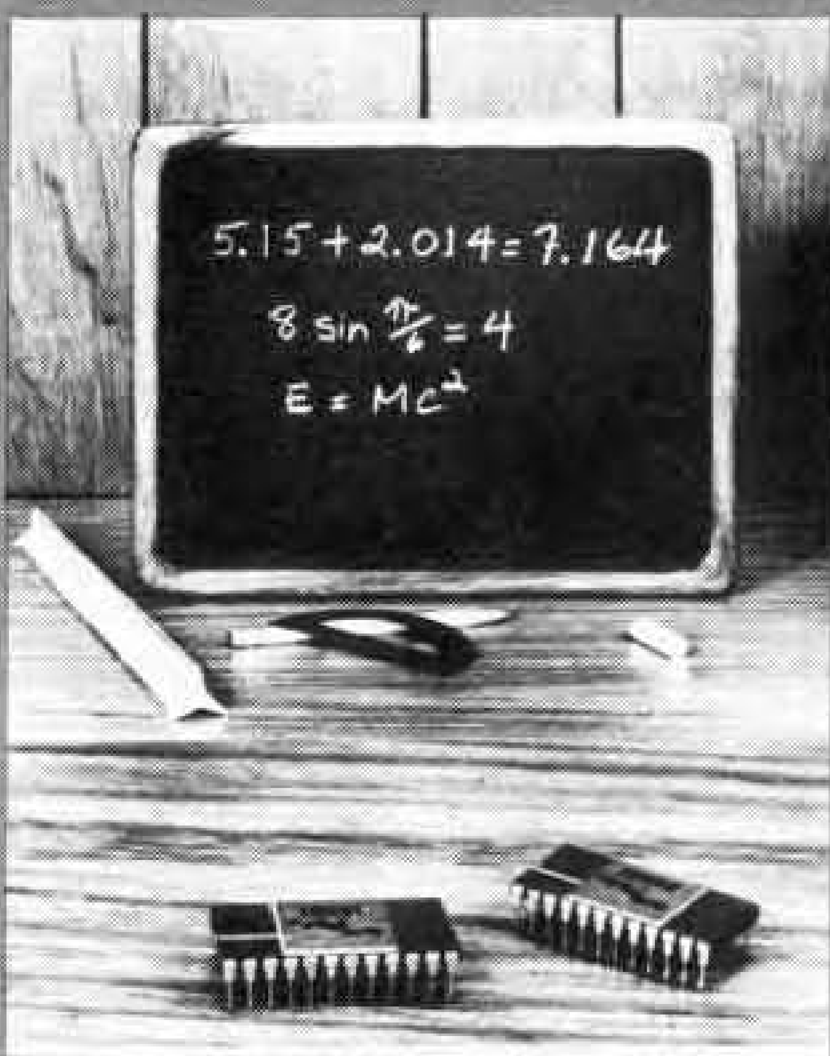


FIG. 1

The 8232 does 64-bit, double-precision floating-point addition, subtraction, multiplication, and division. It can also do 32-bit math at higher speed. Single-precision multiplication takes about 100 microseconds.

The 8231 does fixed point, 16-bit and 32-bit addition, subtraction, multiplication, and division, and can also calculate sine, cosine, tangent, inverse sine, inverse cosine, inverse tangent, square root, logarithm, natural logrithm, exponentials, and powers.

The IC's use a 16-bit arithmetic logic unit, a microprogrammed algorithm controller, an 8 by 16 operand stack, a 10-level working register stack, command and control registers, and a control ROM.

Both devices come in 24-pin packages and require +12- and +5-volt power supplies. They interface to the 8080, 8085, and 8088 microprocessors as well as to other processors with 8-bit data buses. Intel Corporation, 3065 Bowers Avenue, Santa Clara, CA 95051.

Microprocessors

Fairchild's PEP is a low-cost development and evaluation board for the F3870 microprocessor. At $450 it is attractive instrument for industrial, educational, and hobbyist computer applications. The system is useful in debugging hardware and software for F3870, F3872, F3876 and F3878 single-chip microprocessor systems. The PEP's program memory can be downloaded from a cross-assembler running on another microprocessor development system.

The PEP system has a keypad and a six-digit LED display. It interfaces with RS-232C or current-loop terminals at 110, 300 or 1200 baud rates. System firmware supports a high speed paper tape reader for program loading from that medium.

The PEP consists of 2K bytes of static RAM expandable to 4K on board. The board has a 2K ROM-based monitor, memory map strapping options, crystal-controlled system clocks, four general-purpose programmable timers, and four general-purpose interrupt controls. The 2K memory simulates the F3870 ROM and the 4K expansion simulates the larger F3872, F3878 or F3876 ROM's. An additional 128-byte workspace is provided for storing processor registers. Fairchild Camera and Instrument Corporation, 464 Ellis St., Mountain View, CA 94042.

Texas Instruments continues to expand their 16-bit 9900 line with a new 4 MHz processor increasing throughput by one-third. The TMS9900-40 CPU uses separate address and data buses to reduce the delays associated with sharing these two functions on the same leads. This new CPU supports DMA, memory mapped and CRU I/O techniques. (CRU is a command page switching technique allowing memories larger than 65K to be addressed.)

The other devices presently available in the 4 MHz 9900 family are the TIM9904-40 clock generator/driver, the TMS9901-40 peripheral systems interface and the TMS9902-40 asynchronous communications controller. The 9900JL-40 JL CPU is priced at $41.25 each in 100 quantities. **R-E**

UNICORN-1 ROBOT

Part 6—Add some pizzaz to your robot with two different sets of flashing lights. For the more serious-minded, there's also a twist-of-the-wrist end effector.

JAMES A. GUPTON, JR.

YOU SHOULD HAVE YOUR OWN VERSION OF Unicorn-1 in action by now, and have probably been using this time to practice controlling the robot.

In this section, we'll not only describe some simple electronic circuits that will give the robot a more impressive appearance but will provide you, as well, with one of the options promised earlier—a rotatable end-effector.

The next installments of this series will provide circuits that can be used either for radio control (R/C) and/or for computer control—the computer being either part of the robot or external to it and transmitting commands via a radio link.

Before we get involved, though, we'd like to correct an error that crept into Part 2 of this series (September 1980) and that was brought to our attention by several readers: The red and green wires between switch S1 and the barrier strip were transposed in Fig. 18. The red wire should go to ground at the bottom-right of the switch, and the green one to +12-volts at the top right.

It's good to see so many readers taking such an interest in the project!

Electronic embellishments

Flashing lights always attract attention and—you can admit it—that's what you'd like your version of Unicorn-1 to do. We'll consider two different LED-indicator circuits: one to show that the arms are in motion, and in what direction they're moving; the other (just) to attract attention by announcing that Unicorn-1 is "alive."

The first circuit, which shows that the shoulder-motors have been activated, is presented in Fig. 42. You'll remember

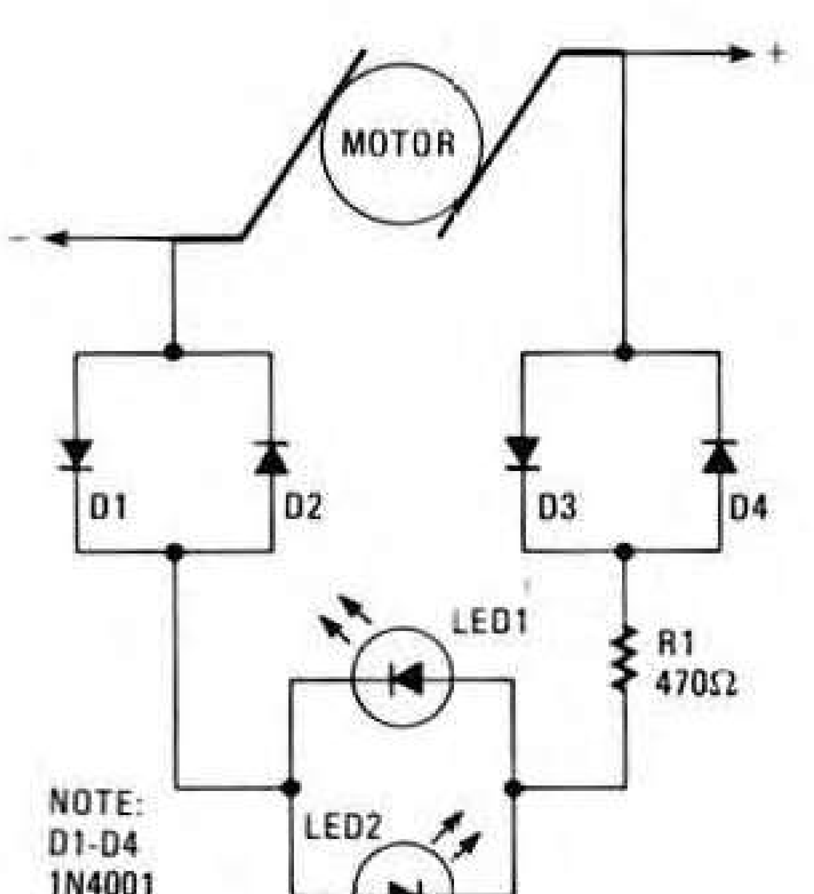
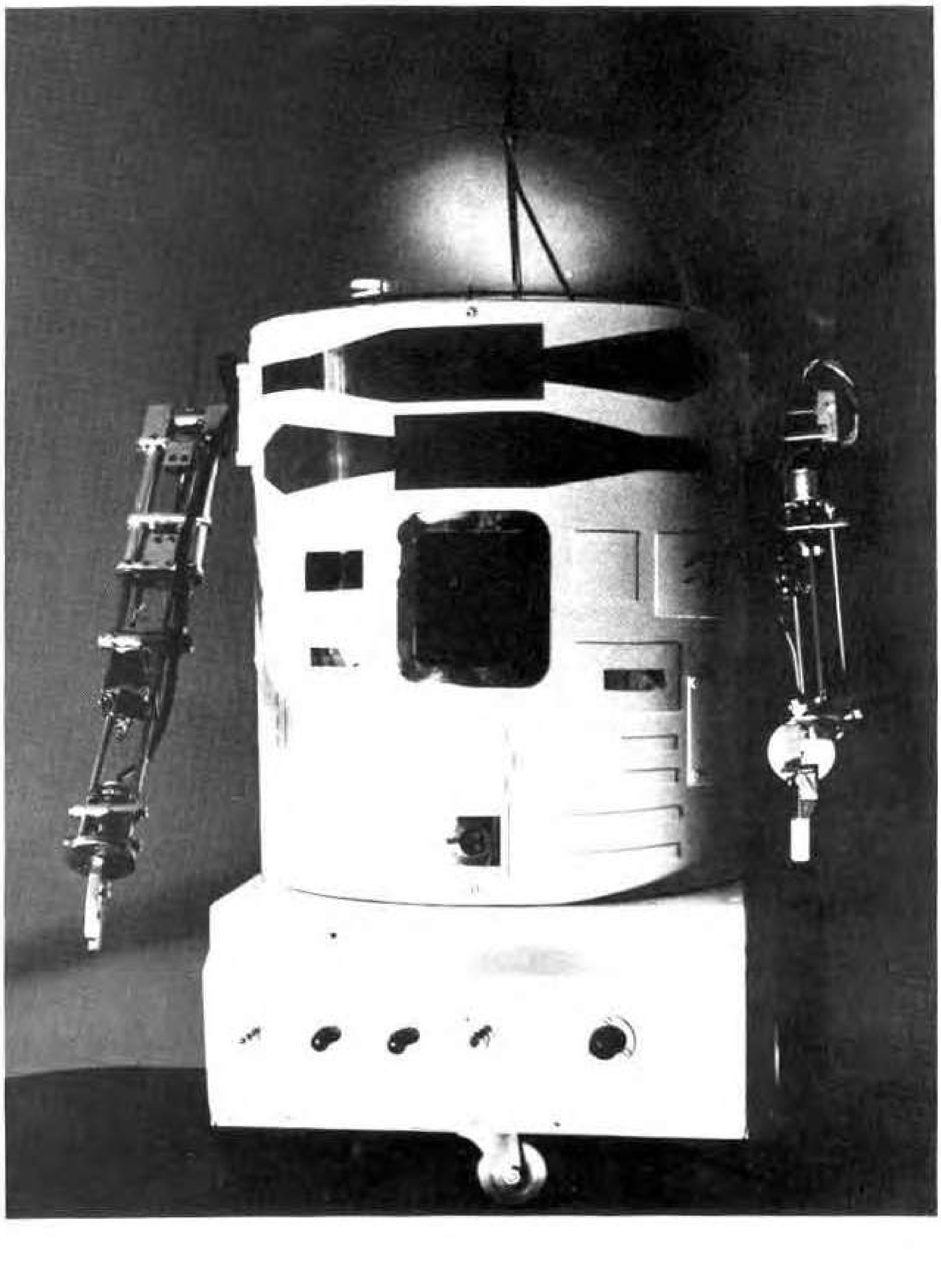


FIG. 42—MOTOR-DIRECTION INDICATOR uses twelve volts. Diodes and resistor reduce voltage and current to safe levels for LED's.



PARTS LIST—MOTOR-DIRECTION INDICATOR

R1—470 ohms, ¼ watt
D1-D4—1N4001
LED1, LED2—jumbo LED's (different colors)

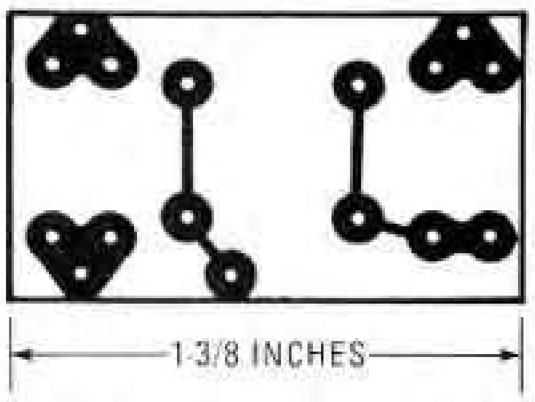


FIG 43—WHEN YOU MAKE THIS BOARD, be sure that pads *do not touch* rectangular border.

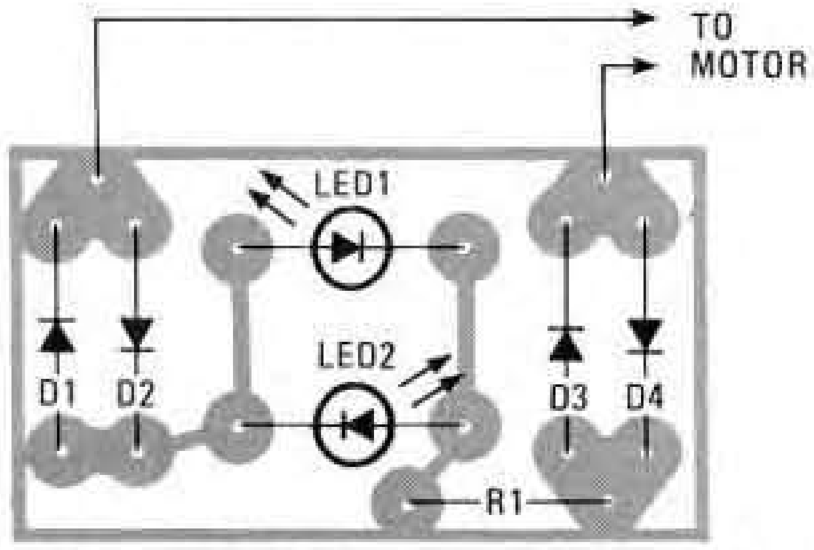


FIG. 44—PC BOARD for motor-direction indicator was designed for rectangular LED's. Circular ones will need their leads bent a bit.

that the direction of motor rotation is changed by reversing the polarity of the current used to power the motor. That circuit detects which way the current is flowing and indicates it via LED's.

Looking at the schematic for the circuit, it can be seen that—if we assume the right-hand terminal to be positive and the other one negative—a stream of electrons will flow through diode D2, LED1, and through D3, causing LED1 to light. (Remember, though, that the current flow is from the positive pole to the negative.) Also bear in mind, as you consider the schematic, that, in a LED—or in any other diode, for that matter—current flows from the cathode to the anode.

Current-limiting resistor R1 is used to prevent burning out the LED's. A value of 470 ohms will be about right to provide the LED with the 20 mA it needs, based on a 12-volt system.

If a command is given to reverse the current flow—where what was previously positive becomes negative—current will then flow through diodes D4, LED2, and D1. Use different colored LED's for LED1 and LED2 so you can tell at a glance which way the motor, and its associated mechanism, is moving.

A foil pattern for the circuit is shown in Fig. 43, and the parts-placement diagram in Fig. 44. Two of those can be built on one board to take care of both arms (see Fig. 45). The LED's used on the board shown in the foil pattern were rect-

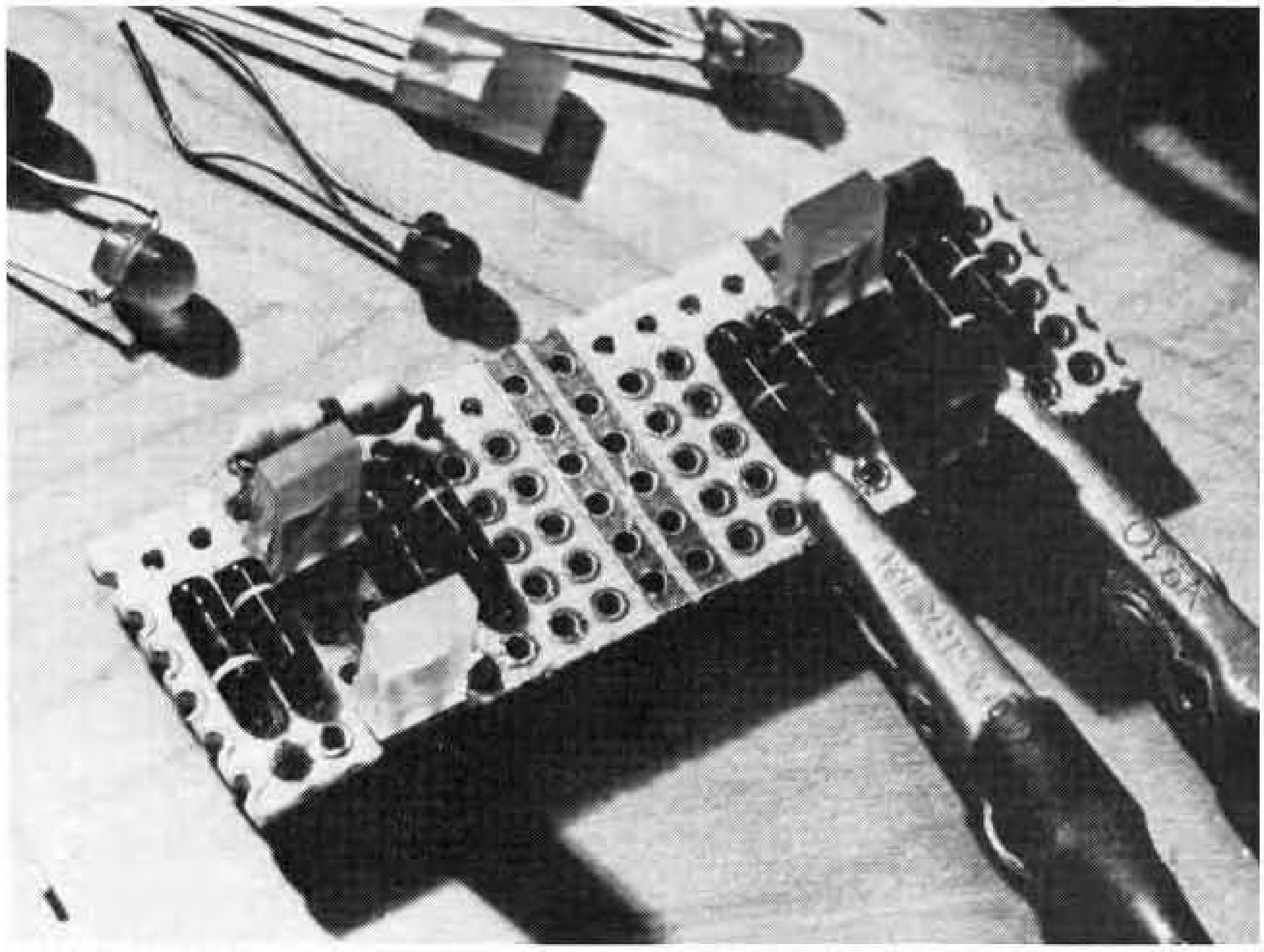


FIG. 45—ONE SMALL PIECE of board holds two complete motor-direction indicators. Current-limiting resistor is visible at top-left of board, above LED.

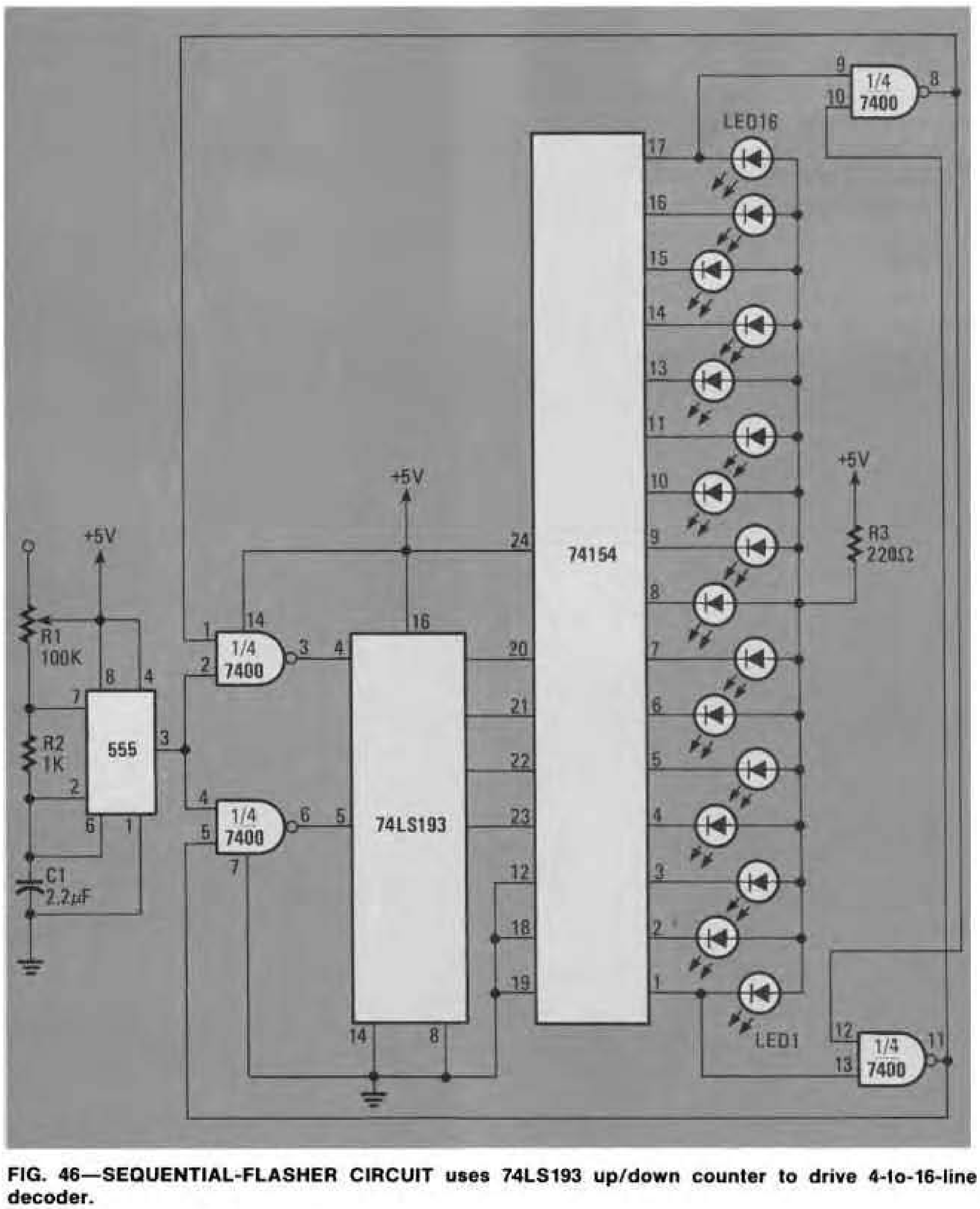


FIG. 46—SEQUENTIAL-FLASHER CIRCUIT uses 74LS193 up/down counter to drive 4-to-16-line decoder.

PARTS LIST—LED FLASHER

All resistors ¼ watt, 5%
R1—100,000 ohms, trimmer potentiometer
R2—1000 ohms
R3—220 ohms
Capacitors
C1—2.2 µF, 16 WVDC, electrolytic
Semiconductors
IC1—555 timer
IC2—7400 quad NAND gate
IC3—74LS193 up/down counter
IC4—74154 4-to-16 line decoder
LED1-LED16—jumbo red LED
Miscellaneous: 7805 voltage regulator with heat sink

angular, which explains the wide spacing of the pads. Round LED's would probably be better, since it is easier to drill round holes in the skin for displays than it is to drill rectangular ones.

One of the best attention getters is an array of flashing lights. One such LED circuit appears in Radio Shack's *ARCHER Engineer's Notebook*, and is the one described here. A display that creates a more random pattern was described in **Radio-Electronics**' Hobby Corner department in the December 1980 issue.

The sequential-flasher circuit in the original Unicorn-1 uses four IC's and five external components to operate 16 LED's. Its schematic is shown in Fig. 46. Resistors R1 and R2, working together with capacitor C1, determine the rate at which the 555 timer IC will cause the LED's to light, and R3 is the current-limiting resistor for the LED's.

The LED's are arranged in five columns of three each (see Fig. 47) with the sixteenth LED at the bottom of the middle column. In operation, they will light starting from the bottom-right, going up the column, then jump to the bottom of the next column, etc. When the last LED has lit, the process will reverse itself, working from left to right and finishing up at LED1.

Although a foil pattern and parts placement diagram (Figs. 48 and 49) are provided, the circuit, and the motor-direction indicator, are both easy enough to build on perforated construction board using wire-wrap techniques. If you have never done any wire-wrapping before, this would be a good place to start because of the simplicity of the circuits. (Articles on wire-wrapping techniques and materials appeared in the August 1979 and March 1980 issues of **Radio-Electronics.**)

You'll need nine jumper wires on the LED-sequencer board. Those can be made from wire-wrap wire, stripped at both ends and tack-soldered to the wiring- or foil-side of the board.

A few words about power supplies for those circuits: TTL IC's are very particular about their working voltage—it should be five volts, ±5% (4.75–5.25 volts). While five volts can be derived

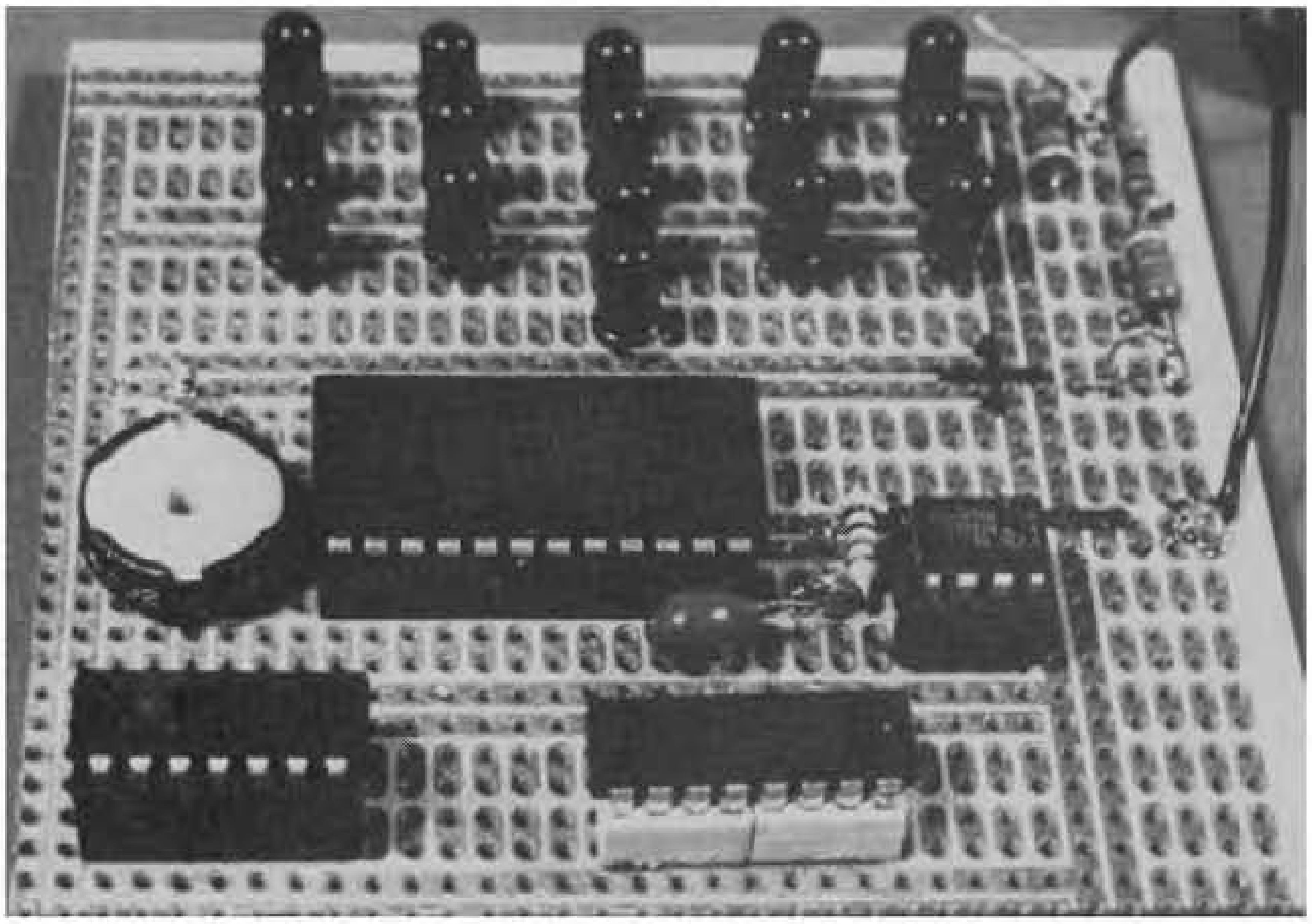


FIG. 47—TRIMMER POTENTIOMETER at left of 74154 IC varies rate at which LED's flash. Mount board so LED's are visible through opening(s) in skin of robot.

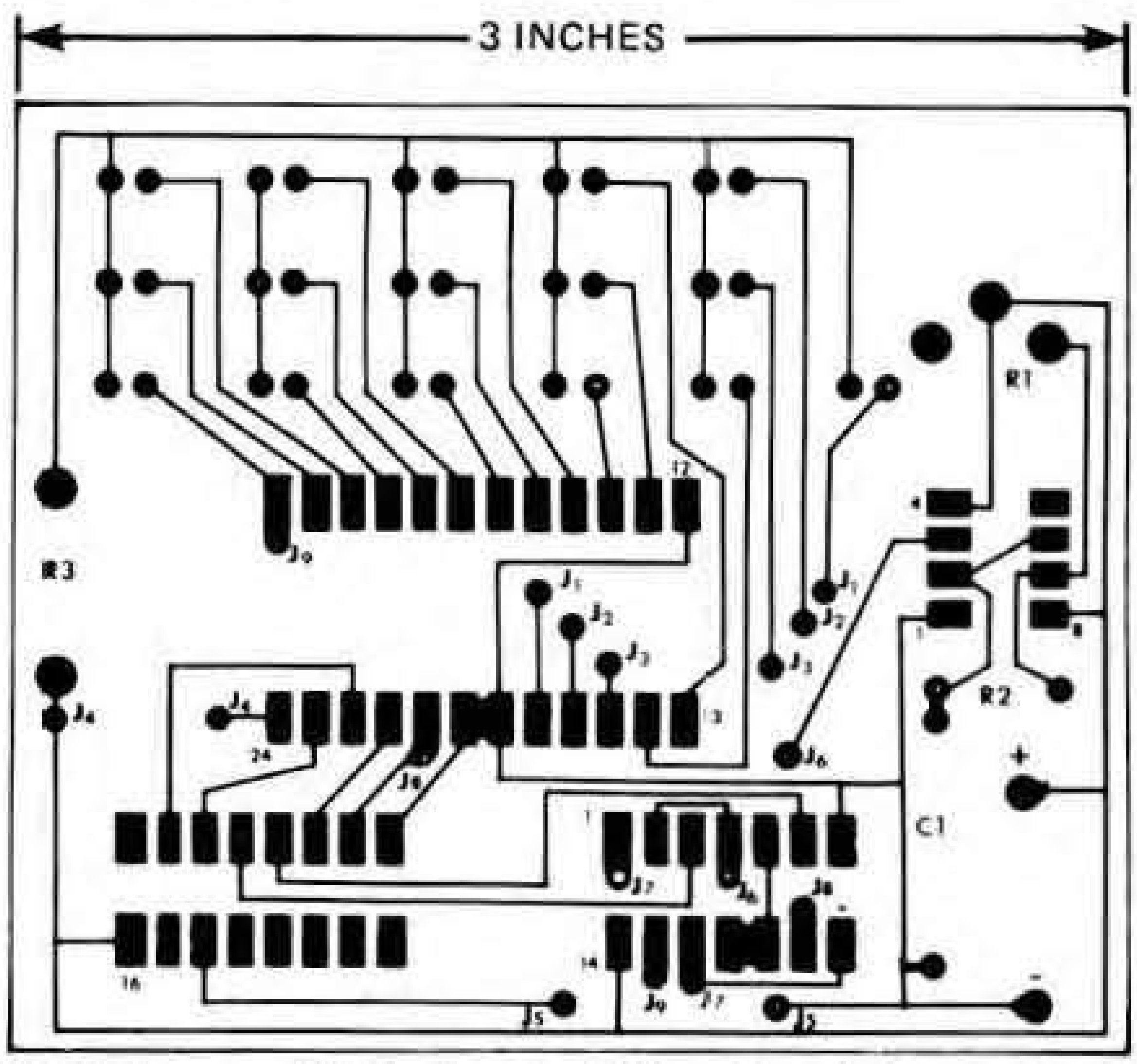


FIG. 48—PC BOARD for sequential-flasher circuit shown in prototype-version above.

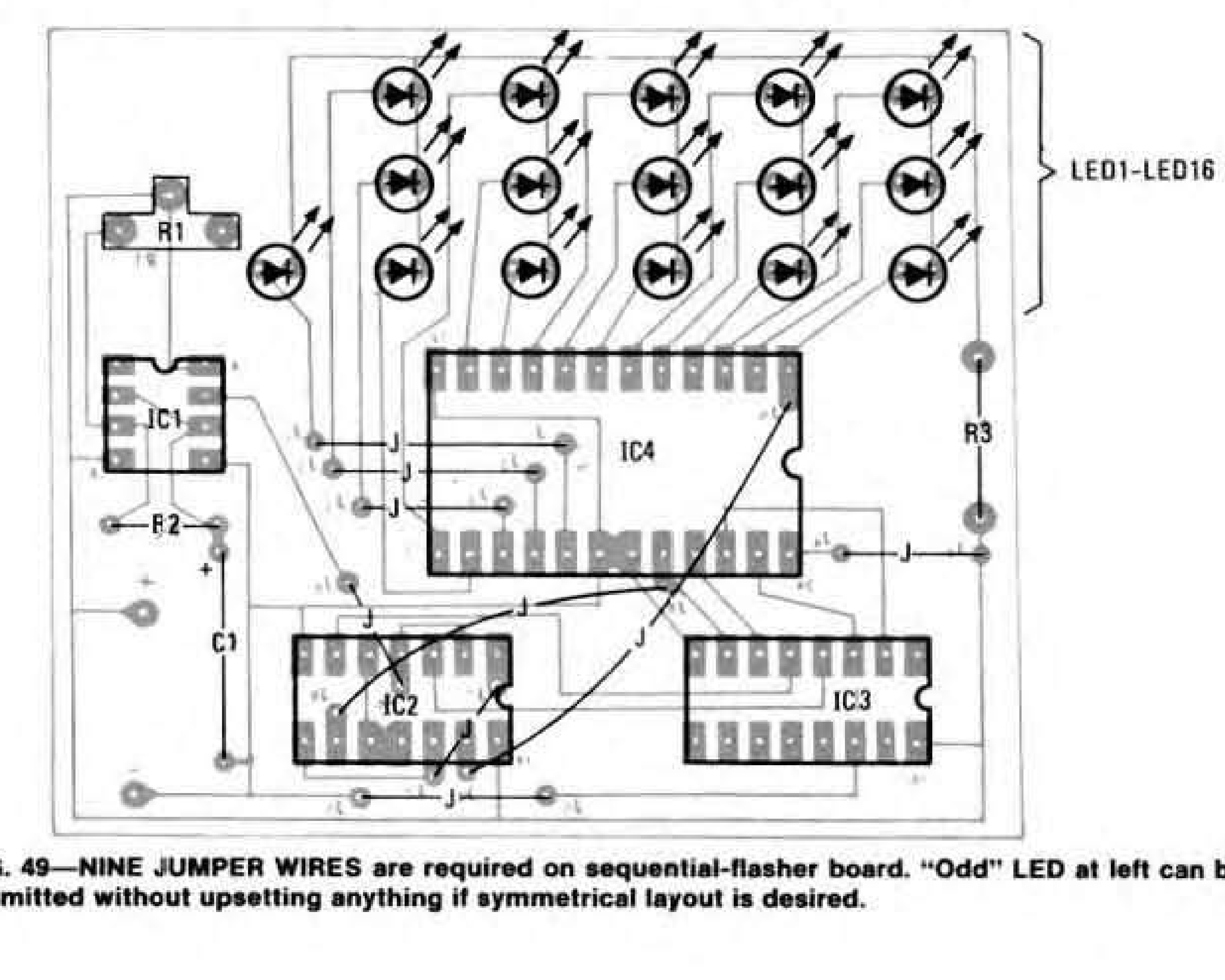


FIG. 49—NINE JUMPER WIRES are required on sequential-flasher board. "Odd" LED at left can be ommitted without upsetting anything if symmetrical layout is desired.

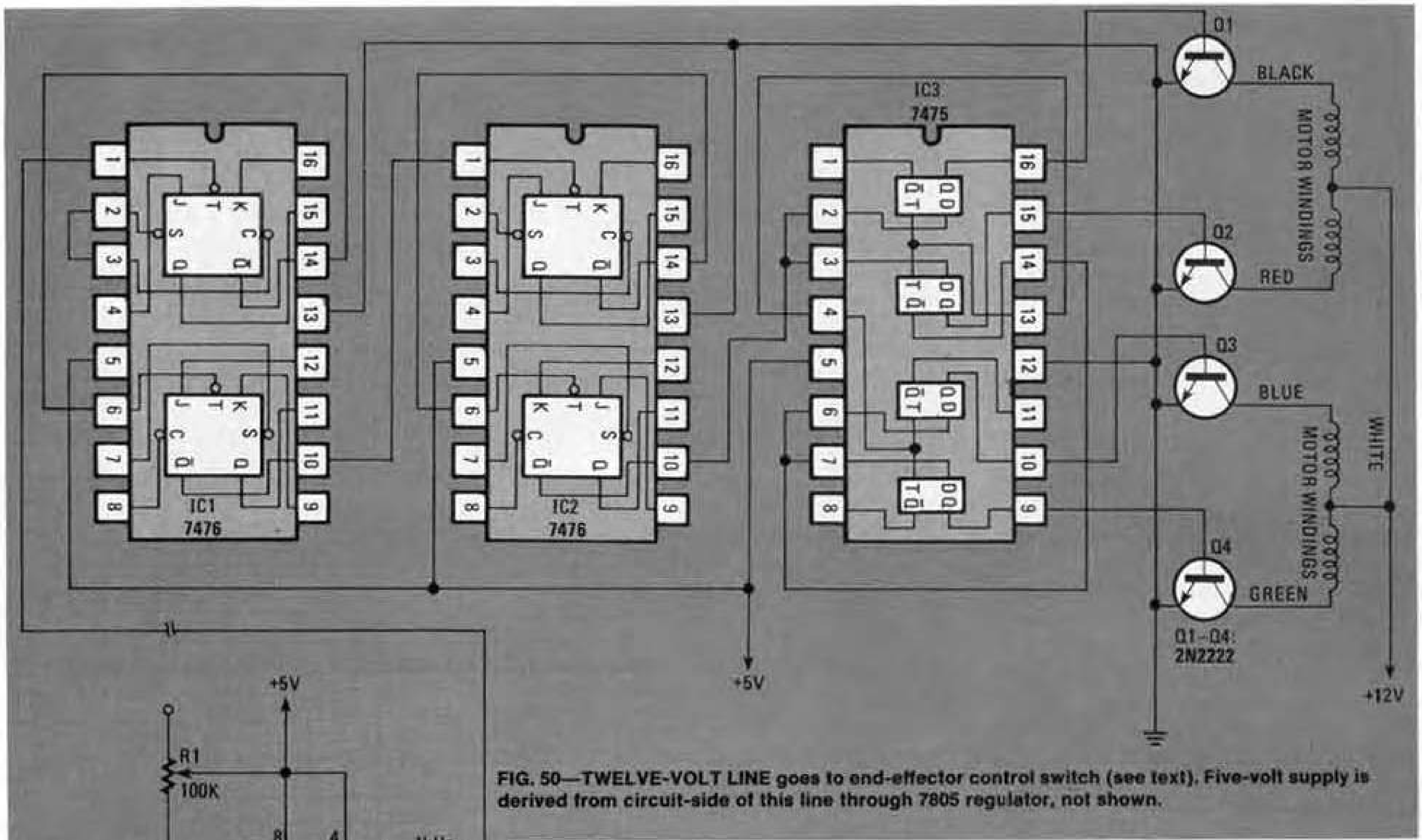
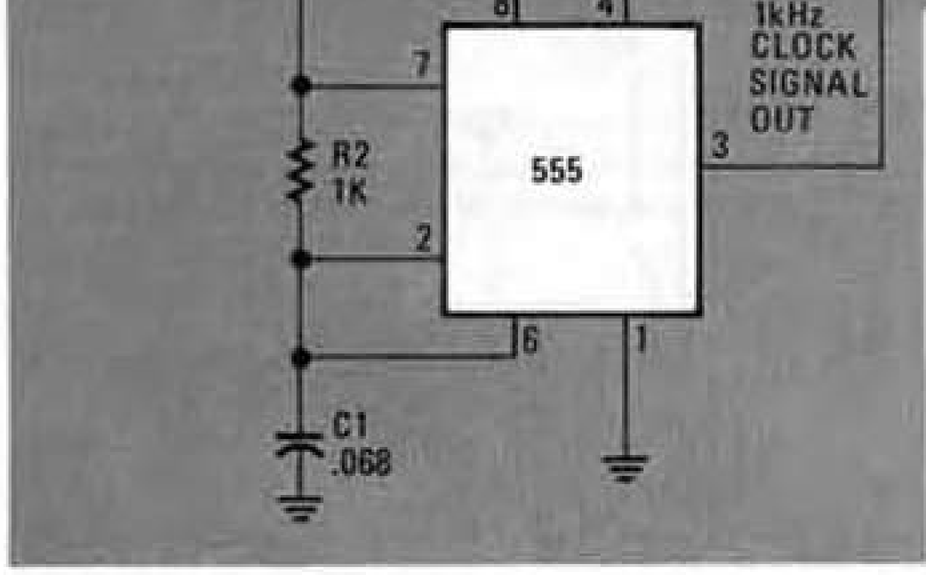



FIG. 50—TWELVE-VOLT LINE goes to end-effector control switch (see text). Five-volt supply is derived from circuit-side of this line through 7805 regulator, not shown.

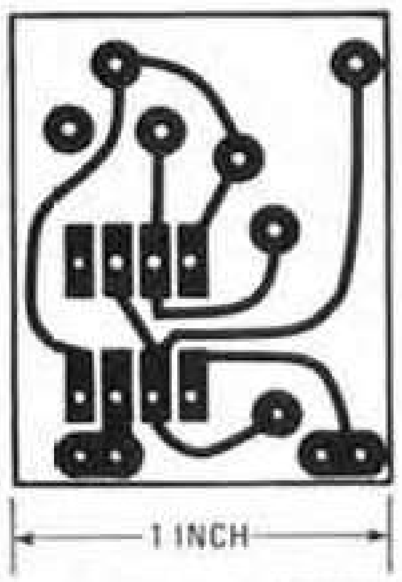


FIG. 51—CLOCK-SIGNAL GENERATOR board for stepper motor controller.

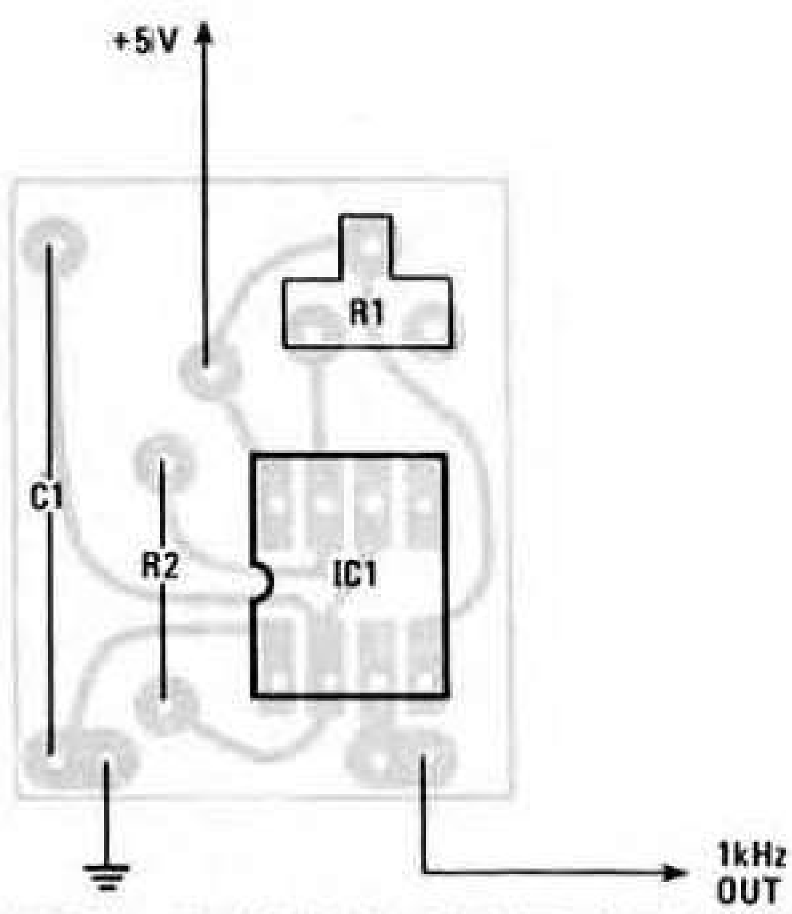


FIG. 52—INTEGRATED CIRCUIT, IC1, is a 555 timer (shown at lower-left in Fig. 50). One-kHz clock signal is fed to second PC board.

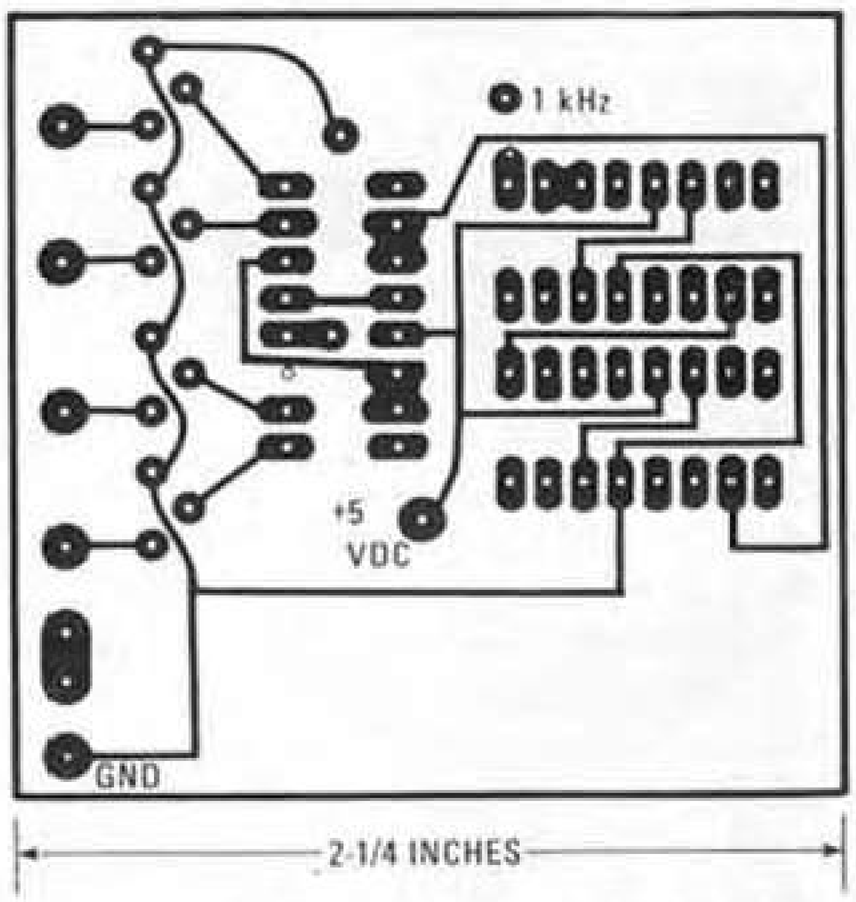


FIG. 53—DIVIDER CHAIN AND LATCHES are located on separate PC board.

from the 12-volt supply by means of a dropping resistor, that method leaves itself open to fluctuations, depending on how much of a load the rest of the robot's electrical and electronic parts present to the battery at any given time. It's better to derive the five volts through a 7805 regulator, well heat-sinked to dissipate the heat generated in dropping the twelve volts to five The addition of an intermediate resistor to drop the 12 volts to eight would ease the load on the regulator.

Other TTL circuits will be described later and they, too, will benefit from a regulated five-volt power supply.

A twist-of-the-wrist

One of the options hinted at earlier in our series was an end-effector (hand) that could be rotated at the "wrist" to give an additional degree of freedom.

That "twist-of-the-wrist" end-effector uses the claw-type mechanism described in Part 2 (September 1980) but, rather than being firmly attached to the manipulator (arm), it is attached to the shaft of a stepper motor. A stepper motor is a motor whose shaft turns just a little bit each time an electrical pulse is applied to its windings.

Figure 50 shows a circuit that generates those pulses and drives the motor. The circuitry actually consists of two parts. The first, used to generate the pulses, is identical to the 555-IC section of the LED sequencer board, except for the values of R1 and C1, which are chosen to give an output of one kHz.

The second uses two 7476 IC's to divide that one-kHz signal by four (giving an output of 250 Hz), and that output is applied to a 7475 quad latch that feeds driver transistors Q1-Q4. Those transistors are connected so as to provide 12 volts to the four windings of the stepper motor.

Figures 51-54 show foil patterns and parts placement diagrams for the two-board circuit. The 12-volt and 5-volt (through a 7805 regulator, not shown) supplies are derived from the wiring to the solenoid of the end-effector mounted on the stepper motor's shaft.

PARTS LIST—STEPPER MOTOR CONTROLLER

All rsistors 1/4 watt, 5%
R1—100,000 ohms trimmer potentiometer
R2—1000 ohms
Capacitors
C1—0.068 μF, 10 WVDC, any type
Semiconductors
IC1, IC2—7476 dual J-K flip-flop
IC3—7475 quad latch
IC4—555 timer
Q1-Q4—2N2222 or equivalent
Miscellaneous: 7805 voltage regulator with heat sink
PC boards for the above are available from PPG Electronics Co., Inc., 14663 Lanark St., Van Nuys, CA 91402. (213) 988-3525: Motor Direction Indicator and Stepper Motor Oscillator, $3.00 each, LED Flasher, $5.00, Stepper Motor Controller, $5.00. Please add $1.00 per order for shipping and handling. CA residents add 6% tax. MC and Visa accepted.

PARTS LIST—STEPPER MOTOR ASSEMBLY

Item	Size	Quantity	Supplier's part no.	Supplier
Stepper motor	12 VDC, 0.9°-step	1	Haydon 31612 or 31618, or equivalent	Ⓛ
Shaft	3/16-in. diam. × 1 inch	1		Ⓚ
Bearing	3/16-in. I.D.	2	B2-9	Ⓐ, Ⓑ
Gear	.593-in. diam., 36-T, 64 pitch, 3/16 I.D.	1	P64A19-36	Ⓐ, Ⓑ
Note: small mating gear comes with stepper motor				
Solid steel wire	20 gauge	5 inches		Ⓚ

SUPPLIERS

Ⓐ **The Robot Mart**
Room 1113
19 W. 34th St.
New York, NY 10001
($3.00 for catalog)

Ⓑ **Winfred M. Berg, Inc.**
499 Ocean Avenue
E. Rockaway, NY 11518

Ⓚ Local hardware or building supplies store

Ⓛ **Haydon Switch & Instrument, Inc.**
1500 Meriden Rd.
Waterbury, CT 06705
(Write for list of distributors)

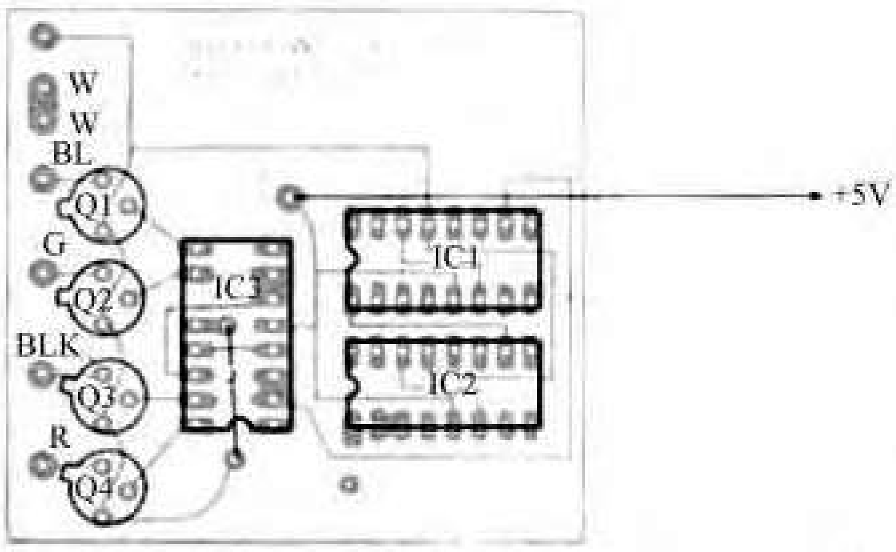


FIG. 54—COLOR CODES shown here should correspond with those on motor wires.

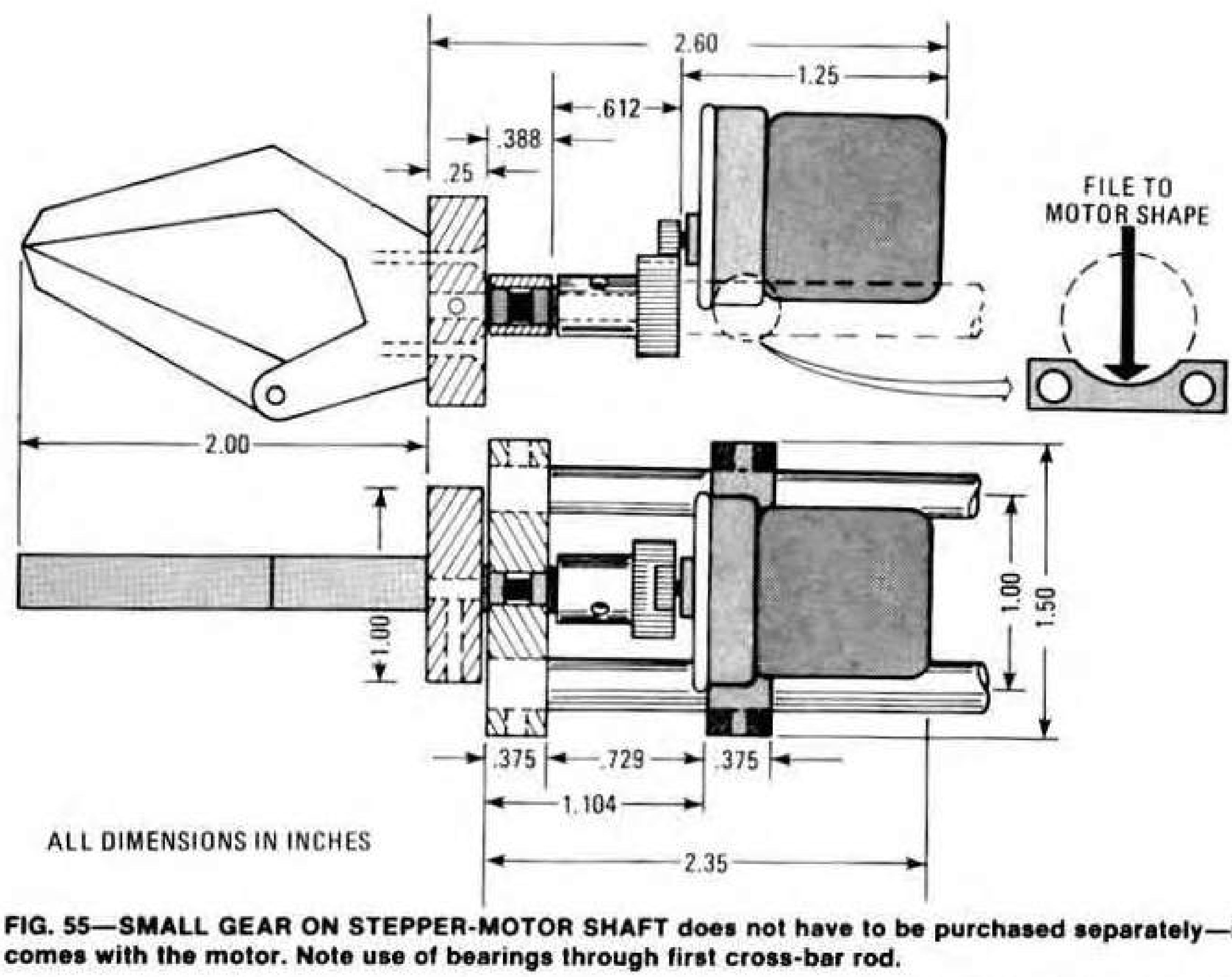


FIG. 55—SMALL GEAR ON STEPPER-MOTOR SHAFT does not have to be purchased separately—it comes with the motor. Note use of bearings through first cross-bar rod.

In practice, when the switch controlling that end-effector is thrown, the "hand" closes and the wrist begins to turn. Returning the switch to the "off" position stops the motor and opens the end-effector. The next time the circuit is activated, the end-effector closes again, but the wrist turns the other way.

The end-effector and wrist actions can be made independent of each other by the addition of another switch to the control console.

Several stepper motors that have been found to work well in this application are indicated in the parts list. The attachment of the motor to the robot's end-effector and manipulator is shown in Fig. 55. A 9-T (nine-tooth), 64-pitch gear is mounted on the shaft of the stepper motor and drives a 36-T, 64-pitch gear attached to the end-effector mounting flange by means of a 3/16-inch diameter shaft passed through two flange bearings in the end cross-bar rod. Not shown in the mechanical drawing is a hole bored through the axis of the shaft to pass the wire that operates the claw. Fig. 56 shows the assembled rotatable end-effector with the 20-gauge solid wire pivoted where it is attached to the solenoid to allow free rotation.

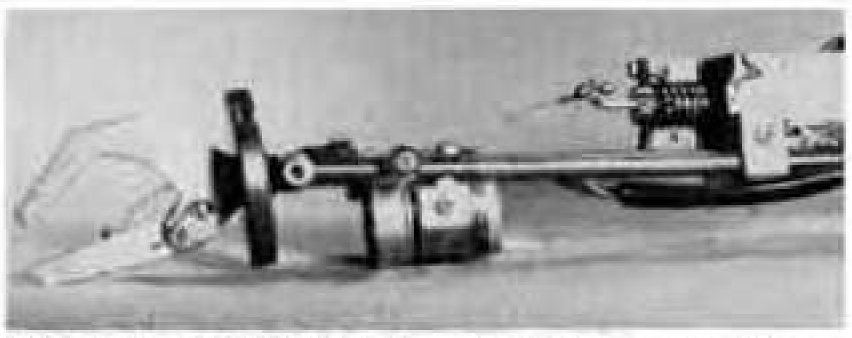
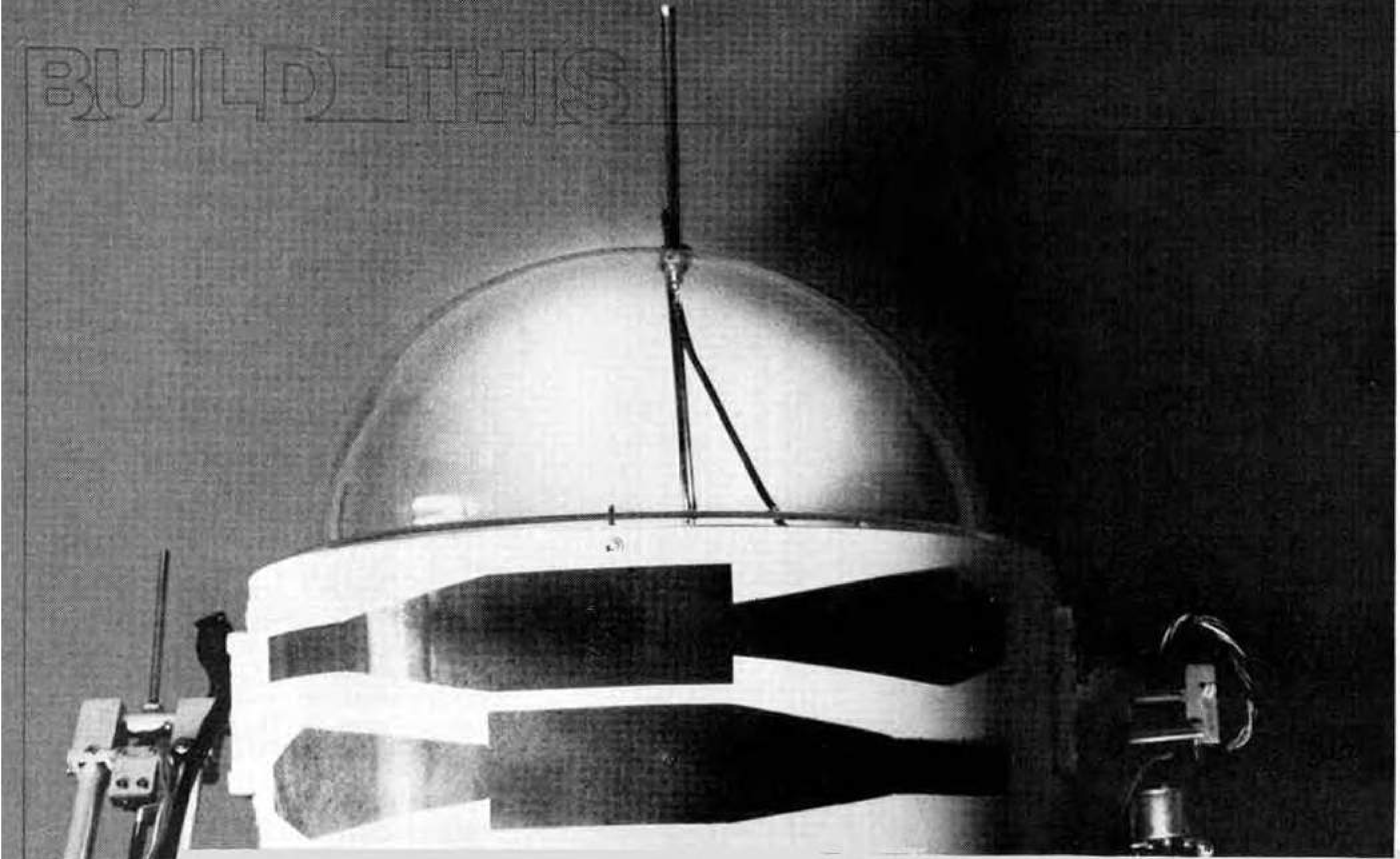


FIG. 56—COMPLETED rotatable end-effector mounted on forearm shows modified connection to solenoid using solid steel wire.

To mount the stepper motor and rotatable end-effector, the end cross-bar rod has to be drilled for the bearings and shaft, and the next cross-bar rod up should be filed to accept the shape of the motor. The motor is clamped and/or bolted to the arm assembly.

In the next installment, in preparation for radio- and computer-control, we'll describe motor-control circuits that operate from logic-level signals, and start making radio-control system. **R-E**



UNICORN-1 ROBOT

JAMES A. GUPTON, JR.

Adding Remote Control

Part 7—The first of several parts on adding remote control to Unicorn-1. The first step is a relay board to drive the 12-volt system from a five-volt source. Also, there's a uniquely robotic arm.

WHILE THE COMMAND CONSOLE AND UMBILICAL cable are fine for getting the feel of controlling the robot, there comes a time when you're ready to break loose and operate the robot from a distance—by radio control, for example. In this section we'll begin the changeover—whether it's for radio or computer control—by constructing a relay board to operate the robot's 12-volt motors and solenoids from 5-volt (logic-level) signals.

We'll also describe another type of manipulator arm for the robot that does away with the elbow-bending action and substitutes for it an *extendable* arm.

Relay board

Both the radio-control decoder circuitry and the computer-interface generate logic-level signals—where the voltages are either close to zero for a logic "0", or close to five volts for a logic "1". Since the motors and solenoids in the robot are designed to operate from a 12-volt supply, we must devise some way of switching 12 volts from a 5-volt control signal. That is the purpose of the relay board.

The board is a standard 22/44 finger (44 fingers, with 22 on each side), 4 × 5-inch perforated IC prototyping board that fits into a mating edge-connector and is available from a number of sources. One side has a foil pad at each of the perforations and two sets of traces for power distribution, but the other is bare, except for the fingers at the card-edge.

Figures 57 and 58 show the same relay board from the foil side with an X-ray view of the relays that are mounted on the bare side of the board. All wiring, with a few exceptions that will be pointed out later, is done on the foil side of the board. Two diagrams will show exactly how the wires are connected.

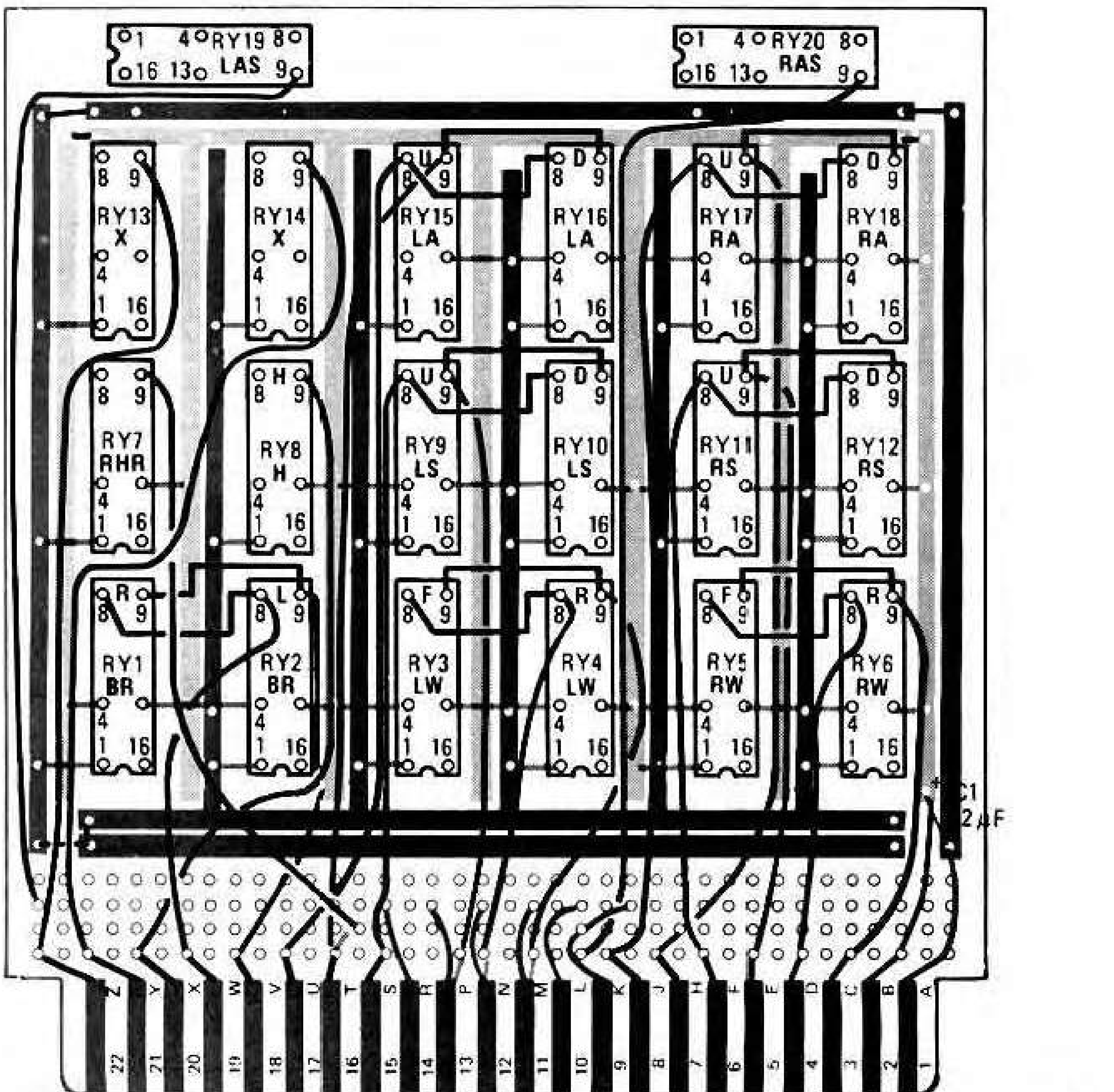


FIG. 57—RELAY COIL CONNECTION to card-edge fingers. Most of the wires go to the relay-side of the board (See Table 2 for specific pinouts).

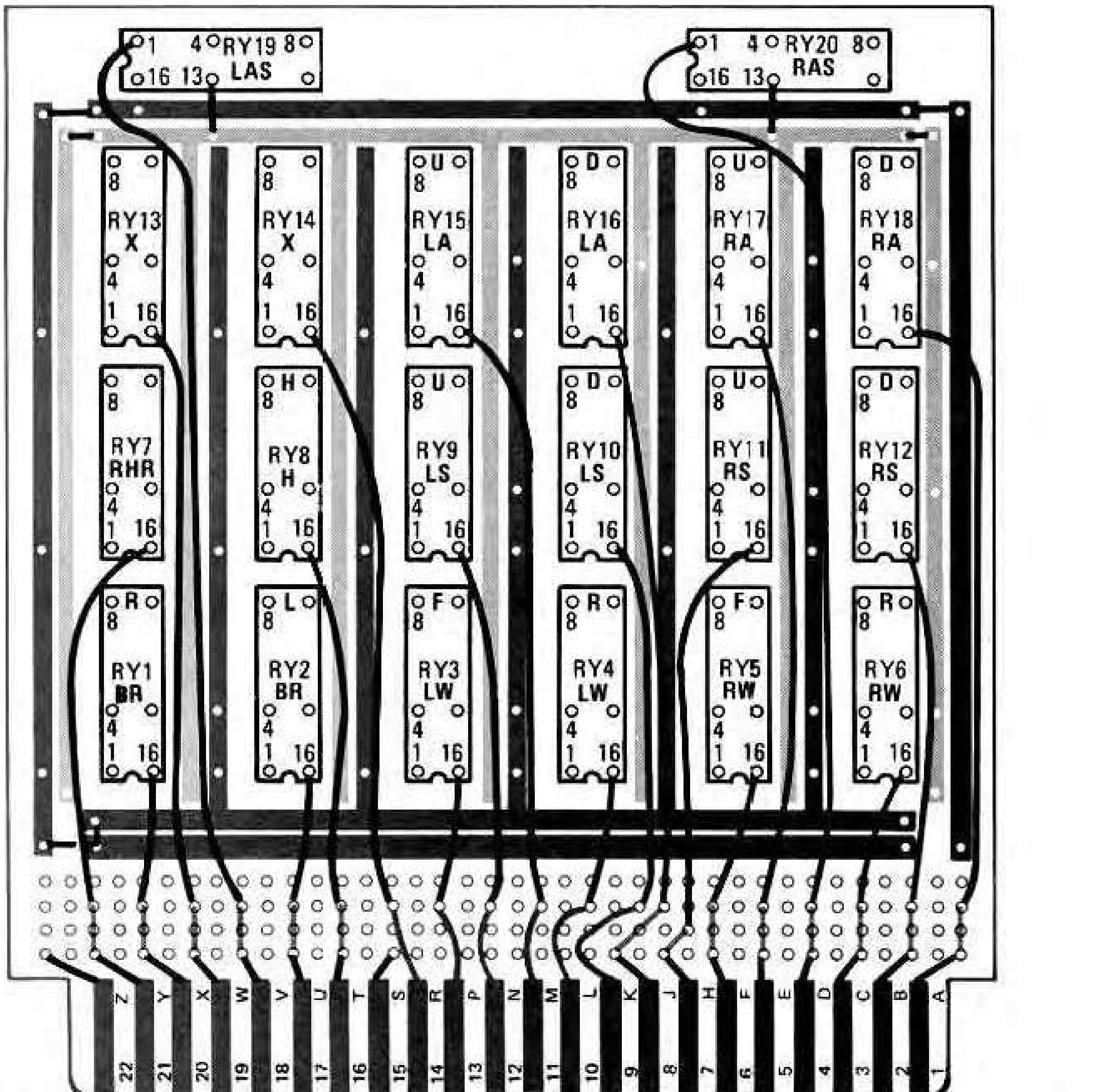


FIG. 58—MOST OF THE REMAINING connections are made on wiring-side of board. See Table 3 for details. Remember: Both diagrams show *foil-side* of board—relays will not be visible!

The DIP relays, capable of switching one amp, (see parts list) are mounted on the bare side of the board in 16-pin DIP sockets. Table 1 shows the function of each of those relays. The sockets can be secured to the board either by soldering their corner pins to the foil pads on the bottom of the board or by a bit of epoxy between the socket and the surface of the board. The first method is preferable. Sockets are used in case the relays have to be replaced.

All 20 relays are the same type, DPDT (see Fig. 59), even though, in some cases, only one section of a set of relay contacts may be used.

It is recommended that, whatever designations (if any) are given to the fingers on the prototyping board you use, you follow the ones given here, to reduce the possibility of confusion and miswiring.

Looking at the foil side and starting from the *right*, the fingers bear the letters "A" through "Z" (with four letters left out to give us 22). The fingers on the bare (relay) side of the board, but *still looking at the board from the foil side*, are numbered 1 through 22, from right to left. (Viewing the board from the bare side would show the numbers 1 through 22, but from *left to right*.) Finger "A" is opposite finger 1, finger "B" is opposite finger 2, etc.

Make sure you understand that system before you start wiring things up!

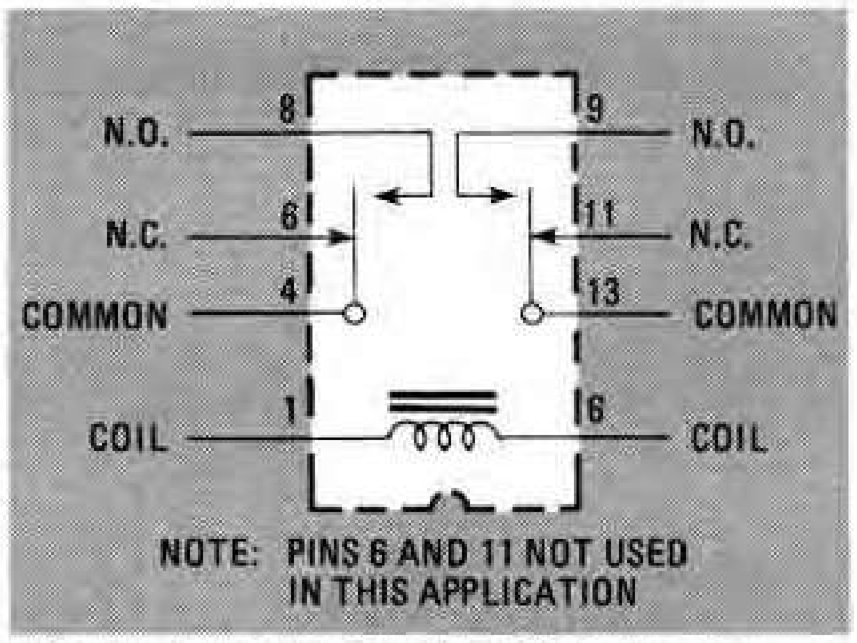


FIG. 59—PINOUT OF RELAYS used in this project by author. Relay contacts should be rated at one amp.

Wiring procedure

Refer frequently to Figs. 57 and 58, and to Figs. 60 and 61.

Begin by connecting pin 1—it feeds one end of the relay's coil—of each of the IC sockets to the ground rail of the board as shown in Fig. 58. The only exceptions to that are relays RY19 and RY20. In their case it is pin 16 that's connected to ground.

Use insulated wire throughout—there are going to be lots of wires, and the possibility of short circuits exists. You can use wire-wrap wire for connections to pins 1 and 16, but all the others will require at least 22-gauge wire to carry sufficient current for the motors and solenoids. Using a color-coding system will simplify signal tracing later.

Next, connect pin 16 (the other end of the coil) of each socket (pin 1 for RY19

TABLE 1
RELAY FUNCTIONS AND CALLOUTS

Relay No.	Function	Designation
RY1	Body rotate, right	BR (R)
RY2	Body rotate, left	BR (L)
RY3	Left wheel, forward	LW (F)
RY4	Left wheel, reverse	LW (R)
RY5	Right wheel, forward	RW (F)
RY6	Right wheel, reverse	RW (R)
RY7	Right hand rotate	RHR
RY8	Horn	H
RY9	Left shoulder, up	LS (U)
RY10	Left shoulder, down	LS (D)
RY11	Right shoulder, up	RS (U)
RY12	Right shoulder, down	RS (D)
RY13	Unassigned	X
RY14	Unassigned	X
RY15	Left arm, up	LA (U)
RY16	Left arm, down	LA (D)
RY17	Right arm, up	RA (U)
RY18	Right arm, down	RA (D)
RY19	Left arm solenoid	LAS
RY20	Right arm solenoid	RAS

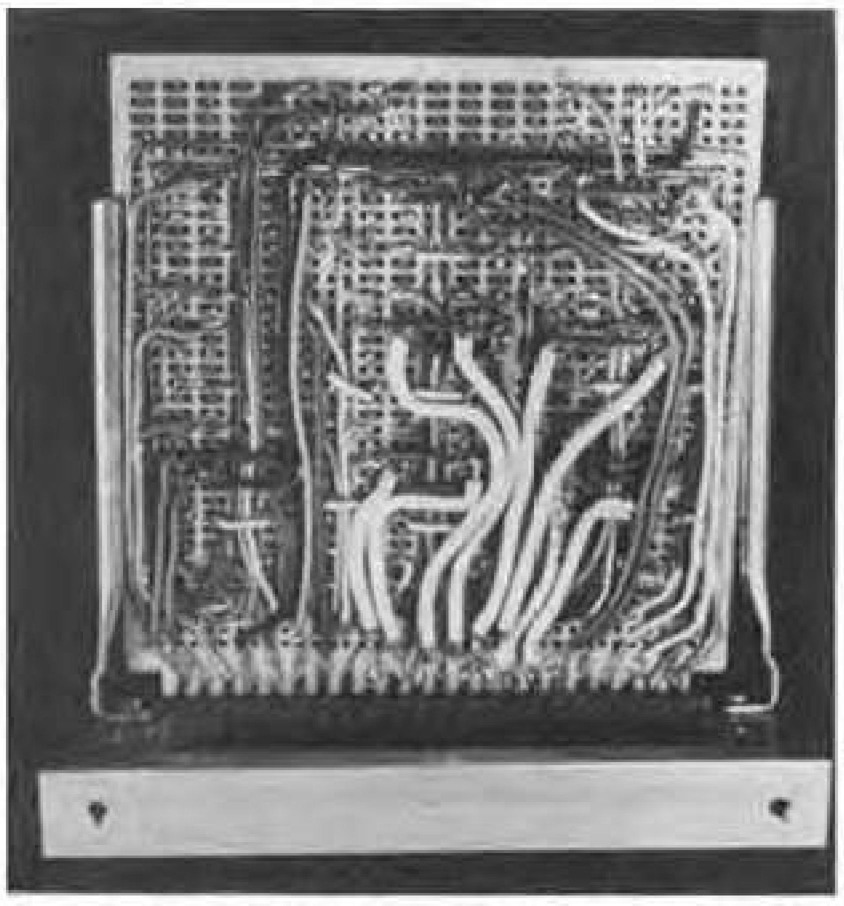


FIG. 60—BE VERY CAREFUL when wiring the relay board and check for shorts and solder bridges. Color coding wires helps.

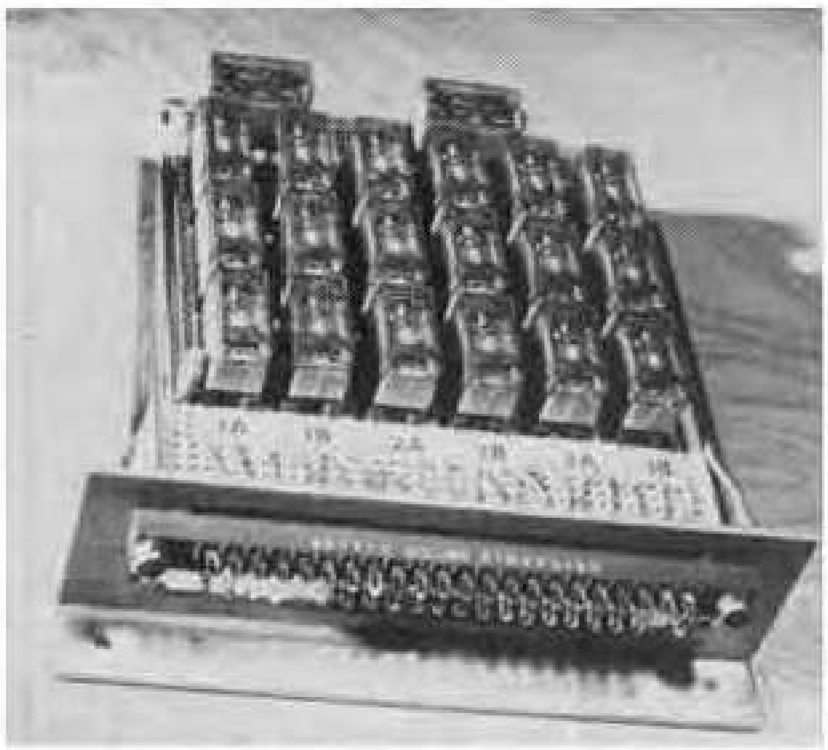


FIG. 61—RELAY BOARD plugs into 22/44 pin edge connector that will be wired to relay-driver board and to 12-volt systems.

and RY20) to the appropriate finger at the card-edge, as shown in Fig. 57 and Table 2. That is part of the exception mentioned earlier—15 of those wires are connected to the fingers on the bare side of the board by passing them through convenient holes. Fig. 61 gives an idea of what that will look like.

You should note that the wires may not run straight down, as is suggested in Fig. 57, but may zig or zag to one side or the other to mate with the pad that connects to the appropriate finger.

A 22 μF tantalum capacitor is mounted on the relay-side of the board and soldered to the 12-volt and ground-supply rails. Make sure that the "+" side of the capacitor goes to the 12-volt line.

The 12-volt rail is connected to finger "B", and the ground rail to finger "A", on the foil side of the board.

Figure 58 shows the connections for the normally-open relay contacts (pins 8 and 9), and those connections are also listed in Table 3. Before making connections to the card-edge fingers, wire the pin 8-to-pin 8, and pin 9-to-pin 9 jumpers shown for some of the relays.

Finally, still referring to Fig. 58, connect pins 4 and 13 to either 12-volts or ground, as indicated.

PARTS LIST—RELAY BOARD

Item	Quantity
22/44-finger, 4 x 5-inch prototyping board (Radio Shack 276-154 or equivalent)	1
DIP relay, 5-volt coil, 1-amp contacts (Radio Shack 275-215 or equivalent)	20
16-pin DIP socket	20
22 μF tantalum capacitor	1
Miscellaneous: wire, solder, etc.	

Finishing up

Inspect the entire board for solder bridges and shorts, and make certain that every wire goes where it's supposed to. The wires should be held close to the board. They can be secured with a drop of one of those very-fast-setting glues, with epoxy, or with silicone sealant.

The operation of the relays can be checked by applying 5 volts and ground to pins 1 and 16 of the sockets or, better still, to the appropriate fingers at the card-edge. You should be able to hear the contacts of the relays click quietly as they close.

The long arm of the . . . robot

A telescoping (or extendable, if you prefer) manipulator was designed to give the robot added versatility as well as an additional unique feature. It replaces the flexing action of the elbow joint (a human attribute) with the ability to "stretch" the arm—something which is definitely not a characteristic of people, or of most other animals.

Refer to Fig. 62 as the construction of this new arm is described.

First, the manipulator with the claw-type end effector (that can even be the one with the rotatable wrist) is removed from the robot at the shoulder, and the entire upper section—from the elbow hinge to the shoulder-attachment section—is disassembled. Only the two side rods, the elbow-hinge cross-bar rod, the ¼-20 threaded rod and limit switches are re-used. Hold onto the other parts, though—you may find a use for them later. (That's one of the prime rules of scrounging.)

The first step after that is to cut two ½-inch diameter aluminum rods six inches long, and to bore a ¼-inch hole through the entire length of each. Those holes must be true, so work very carefully and slowly.

Next, the two ¼-inch diameter side-rods that were removed from the original arm are cut to a length of six inches, as measured from the elbow-hinge end. (This end will be reattached to the shoulder motor later.) Each of those rods will then be mated to one of the ½-inch diameter rods by lapping the two until a smooth sliding action is achieved.

That lapping (which is the process of rubbing the two pieces together until all excess material has been worn away and they fit smoothly together—and, incidentally, is the way telescope mirrors are made and polished) is accomplished by applying a polishing compound to the inside of the bore hole in the aluminum rod and moving the ¼-inch steel rod in and out of the hole while rotating it slow-

TABLE 2 RELAY COIL WIRING		
Relay	From pin no.	To finger no.
RY1	16	20
RY2	16	17
RY3	16	R
RY4	16	M
RY5	16	6
RY6	16	3
RY7	16	21
RY8	16	16
RY9	16	P
RY10	16	L
RY11	16	7
RY12	16	2
RY13	16	15
RY14	16	19
RY15	16	N
RY16	16	8
RY17	16	5
RY18	16	1
RY19	1	18
RY20	1	4
Ground trace	—	A
12-volt trace	—	B

TABLE 3 RELAY CONTACT WIRING		
Relay	From pin no.	To finger no.
2	8	W
2	9	V
4	8	12
4	9	11
6	8	D
6	9	C
7	9	16
8	9	X
9	8	S
9	9	13
11	8	F
11	9	E
13	9	Z
14	9	Y
15	8	U
15	9	T
17	8	J
17	9	H
19	9	22

ly with an electric drill. (Ordinary automobile rubbing compound will work very nicely.)

A note of caution: The roughness left by boring the hole can, and probably will, grab the rotating steel rod and wrench the aluminum rod out of the clamp you are using to hold it. An indication that that is about to happen is an increase in the temperature of the aluminum rod that you can detect with your hand. Check for that frequently and, as soon as you notice it, either slow the speed of the drill or remove the steel rod and stop work until things cool down.

The job is finished when the steel rod slides smoothly within the aluminum one. **Stop at that point!** If you continue, the fit will become sloppy and the parts may jam when in motion.

Another note of caution: Each set of rods that is lapped must be kept together as a matched pair. A steel rod that has been lapped in one aluminum rod (now a tube) will not mate well with another!

The next step is to prepare two square posts (made from 3/4-inch square extruded aluminum material with 1/8-inch walls) to attach the new arm to the shoulder motor cross-bar rod.

The length of each post is 1 1/2 inches. One end of each post should be filed so that the walls, which were originally 1/8-inch thick, are reduced to a thickness of 1/16-inch. Fortunately, that only has to be done for the first quarter-inch of the post. Drill a 1/2-inch hole in the other, unfiled, end, so that its outer edge is 1/4-inch from the end of the post.

Four cross-pieces now have to be prepared. The first is the shoulder-hinge plate, shown at the upper-right of Fig. 62. It might be worthwhile to refer back to Parts 1 and 2 of this series (August and September 1980) to review the metal-working techniques presented there.

From a piece of 1/4-inch aluminum plate cut a piece 2 1/2 × 1/4-inches. (Those are the final dimensions—remember to allow for wastage.) Mark two 3/4-inch-square openings at the ends of the piece leaving 1/8-inch clearance from the edge (see Fig. 62).

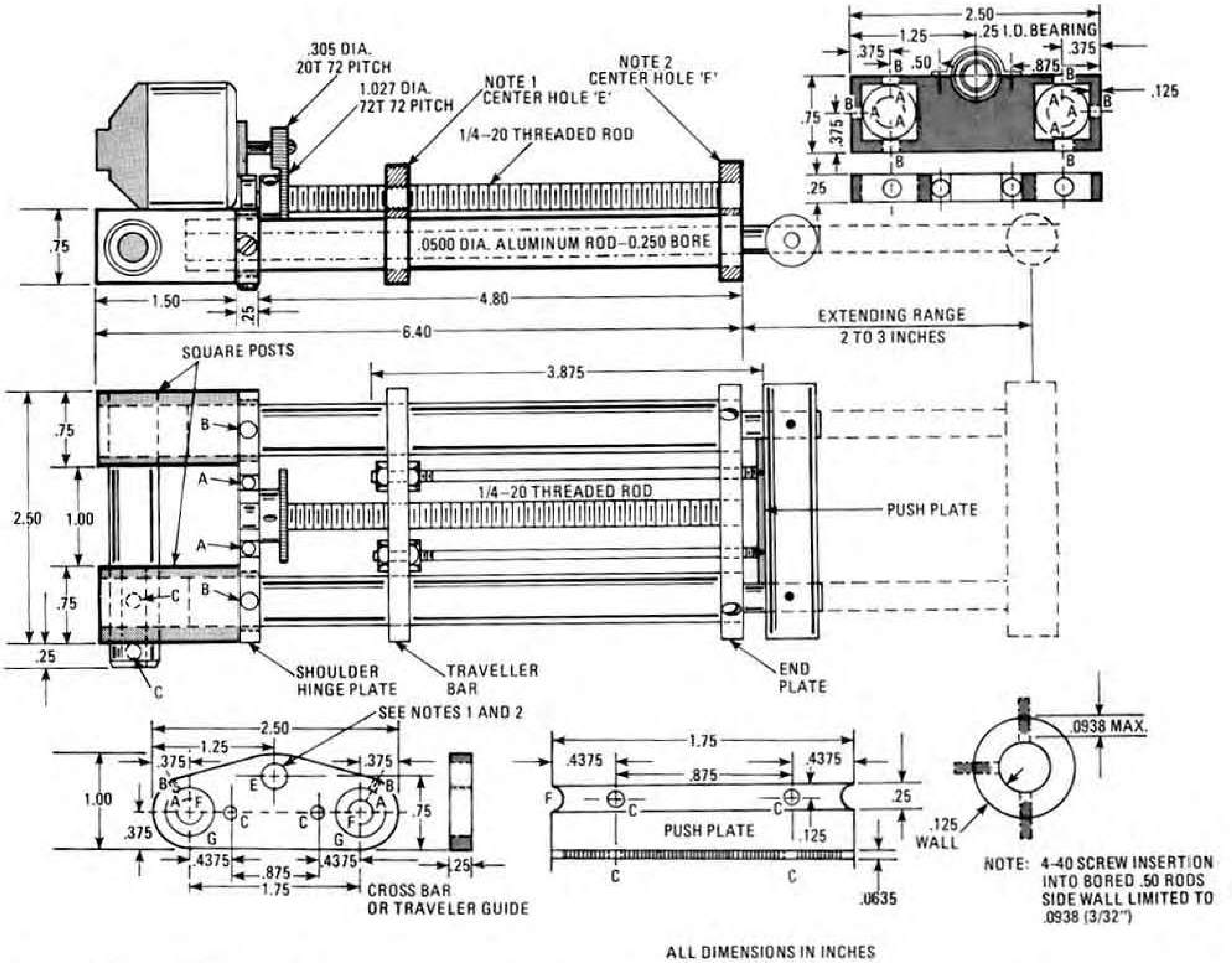
You can cut out those openings by drilling a series of small holes along the inside of the lines you marked and then cutting or drilling through the "webs" between the holes to remove the center piece. Then, using a warding file, finish the opening, from time to time checking the size of the opening by fitting the *filed end* of the square post that will eventually go into that hole into it. The objective is a snug, push-in, fit with no play. Once the post is in the opening, it should not be able to be removed without some effort.

When both square holes are completed to your satisfaction, a recess must be made in the top of the piece to seat the bearing that will hold the end of the 1/4-20 threaded rod.

That bearing can be one of two kinds. It can either have an inside diameter of 1/4-inch that will accept the threaded rod as it is or, it can be smaller and the rod turned or filed down to fit it. The first approach will give more strength, and is recommended. After marking the position the bearing will occupy (the center of the bearing's opening even with the top of the bar, and the bearing in the middle of the bar), the semicircle can be cut using the drill-and-file technique described above or the metal can simply be filed away until the desired shape is obtained.

A 1/4-inch-wide strap of aluminum or

PARTS LIST—EXTENDER ARM				
Item	Size	Quantity	Supplier's part no.	Supplier
Aluminum side rod	1/2-in. diam. × 6-inch	2	AB-6	Ⓐ
1/4-inch aluminum plate	1 1/4 × 2 1/2-inches	2	APS-1	Ⓐ
Aluminum or brass plate	1/16 × 1/4 × 2 1/4 inches	1		Ⓚ
	3/4 × 2 1/2-inches	1	APS-75	Ⓐ
Bearing	1/4-in. I.D.,	1	B2-10	Ⓐ, Ⓑ
3/4-in. square aluminum post	1 1/2-long	2		Ⓚ
Push rod	4 in. 1/8-in. diam., long, threaded 8-32 both ends	2		Ⓚ
Gear	.305-in. diam., 20-T, 72 pitch	1	P72A-20	Ⓐ, Ⓑ
	1-in. diam., 72-T, 72 pitch	1	P72A-72	Ⓐ, Ⓑ



DRILL & TAP KEY			
A 43 DRILL–TAP 4-40	C 29 DRILL–TAP 8-32	E 7 DRILL–TAP 1/4-20	G 0.500 DRILL OR
B 33 DRILL (BODY DIA. 4-40)	D 19 DRILL (BODY DIA. 8-32)	F 0.250 DRILL (BODY DIA. 1/4-20; 0.2497)	DRILL 0.375, REAM TO 0.500

FIG. 62—USE THESE DIAGRAMS, together with instructions given in text, to build extender arm. Counterweight is not shown, but attaches to last cross-bar rod.

brass will be used to hold the bearing in place. With the bearing temporarily in position, bend the strap over it and mark a spot at each end of the strap for a mounting hole. Use a #33 drill bit to make these holes in the strap.

Then, mark *through* those holes to the edge of the plate, on either side of the semicircular cutout. Drill holes at those points using a #43 drill, and tap them to accept 4-40 screws. Do not mount the bearing yet—several more holes still have to be drilled in the plate.

Mark three drilling points in the edge of the aluminum plate for each square post so that the holes drilled will intersect each side of the square posts in the middle. Then insert the posts into the square holes, tapered-end first, and drill completely through the aluminum plate and the side walls of the posts using a #33 bit. You should wind up with six holes in all.

Now take a break and polish the two six-inch drilled-out aluminum rods to a high luster. That not only gives a good appearance, but also insures that the traveler bar (see below) will move freely.

Then insert one of the six-inch rods into the square opening of one of the posts (from the *unfiled* end) for a distance of 1/2-inch. Drill completely through the three holes previously drilled (through the plate and the square posts) into the aluminum rod with a #43 bit. Tap those holes for 4-40 screws. Do the same at the other square opening.

Attach the rods to the square posts using 4-40 machine screws *no longer than 9/32-inch*. The reason for limiting the length of those screws is to prevent their biting into the sliding steel rods and impeding their motion. Set the assembly aside for a while.

The next two cross-bar pieces, the end plate and the traveler bar, are both made from 1/4-inch aluminum plate, 2 1/2 × 1 1/4 inches, and filed to shape as shown in Fig. 62.

They are essentially the same, but have the following differences: The center hole in the end plate is simply made with a 1/4-inch bit. The center hole in the traveler-bar, however, must be tapped to 1/4-20 to accept the threaded steel rod. (Drill that one with a #7 bit before tapping.)

Another difference is that, while the 1/2-inch holes in the traveler-bar for the slide-rods must allow those rods to travel freely through them, their counterparts in the end-plate are cross-drilled, using a #43 bit, and tapped for 4-40 screws, to hold the plate in position on the rods.

Finally—and this holds true for both pieces—two holes are drilled in each, on the center line, and 7/16-inch from the center in each direction. Those holes are made with a #29 drill and are tapped to 8-32 to accept the two four-inch push rods, threaded on both ends.

The last piece to be fabricated is the push plate, which is made from 1/16-inch aluminum or brass plate, 2 1/4 × 1/4-inches in size. Mark a center line along the long dimension of the flat side of the plate. Then, measure 7/8-inch in from both ends along this center line, and drill 1/4-inch

continued on page 97

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continued from page 63

holes at both points. Cut off the excess end-material to leave semicircular openings with a 1/4-inch diameter.

Drill two 1/4-inch holes, 7/16-inch from each edge of the plate for the push rods, and tap them for an 8-32 thread. Finally, drill another 1/8-inch hole at the exact center of the piece, and tap it to 8-32, as well. That hole will be used to attach the push plate to the forearm.

Position the push plate against the steel cross-bar rod that used to belong to the elbow and, using a center punch, mark the exact center of the hole that was just drilled in the push plate. Set the push plate aside and use a #19 drill bit to drill completely through the cross-bar rod. The push plate will be attached to the cross-bar rod using a 1/4 × 8-32 screw inserted, of course, through that rod into the threaded hole in the plate.

Final assembly

Cut the 1/4-20 threaded rod from the original arm to a length of five inches. That rod is pushed through the end plate and threaded into the traveler plate for approximately two inches. Install the two four-inch push rods and secure them to the traveler bar with 8-32 hardware.

Secure a shoulder-lock gear (1 inch, 72-T, 72-pitch) to the upper-end of the threaded rod and, having inserted the threaded rod into the bearing, clamp the assembly into place on the shoulder-hinge bar.

Replace the motor that originally drove the threaded rod with a small 12-volt DC miniature motor (see parts list) and attach a 0.305-inch, 20-T, 72-pitch gear to its shaft. Secure the motor to the outside square bar on the shoulder-hinge mount and attach the square bars (and the arm they're attached to) to the shoulder motor as shown in Fig. 63.

Limit switches can be installed on small aluminum plates attached to the end plate and mounted under the motor, which is fastened to the aluminum bar mounting-post. Those limit switches take the place of the ones that are used in the flexing-elbow assembly and are wired accordingly.

The additional weight of the manipulator may present too great a load for the shoulder motor to handle. If that is the case, a lead counterweight can be fabricated and attached to a rod inserted into the shoulder assembly and extending backwards from the joint as shown in Fig. 64. Move the counterweight back and forth until the motor operates without strain.

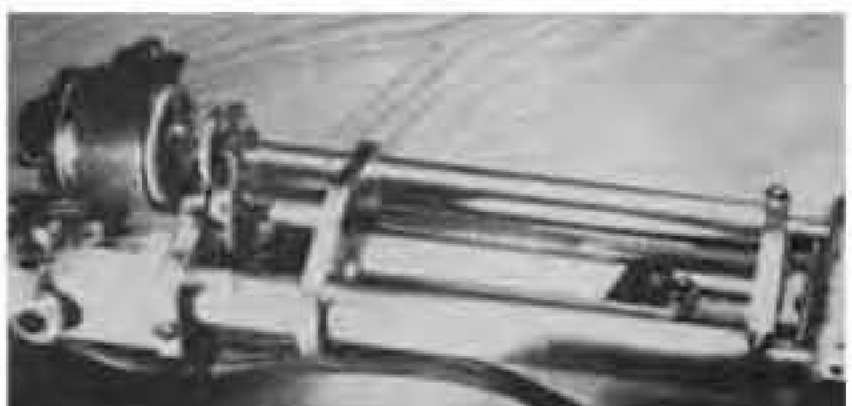


FIG. 63—COMPLETED EXTENDER ARM shows how new motor is attached and how it is connected to drive threaded rod.

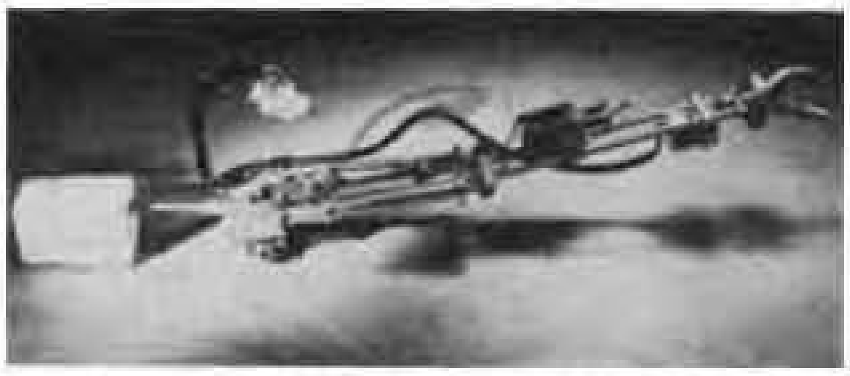


FIG. 64—LEAD COUNTERWEIGHT (left) is used if weight of entire arm assembly puts too much strain on shoulder motor.

Coming up

The next two sections of this series will give instructions for building the relay-driver board that supplies 5-volt signals to the board described here; for building a *Touch Tone* encoder to generate signals for remote-control operation; for the companion decoder that supplies logic-level signals to the relay-driver board, and for an FM transmitter to get the signals from the encoder to the decoder.

And, for everyone waiting to let his computer do the work, the relay-driver board will also accept instructions from the computer's parallel port.

Just wait till you see what's coming up! **R-E**

UNICORN-1 ROBOT

Part 8—Last month we began to look at a remote-control system for the Unicorn-1 robot. In this part we will continue with that system by describing our control scheme, a simple FM transmitter, and a relay-driver board.

JAMES A. GUPTON, JR.

A LOT OF THOUGHT WAS GIVEN TO HOW Unicorn-1 could be controlled remotely. A number of schemes were considered—ultrasonics (not reliable enough and not enough range); infra-red (the same, but more so), and, of course, radio. A system was even devised using model-airplane R/C equipment, but that proved to be expensive and not easily expandable to computer-control.

The system finally chosen was inspired by one used by amateur radio operators for VHF and UHF repeater control and its principles are probably familiar to most **Radio-Electronics** readers from at least one other source—the telephone company.

Before getting into the actual construction of the robot's R/C system, it might be a good idea to fill you in on this scheme, so you have an idea of the direction we're headed in.

The heart of the system is the DTMF (*D*ual *T*one *M*ulti-*F*requency) system—also known as *Touch-Tone*. A 16-key pad (shown in Fig. 65)—or a matrix of switches providing the equivalent function—is used to instruct a DTMF generator IC, in this case a ICM7206JPE, to produce a pair of tones unique to the key pressed.

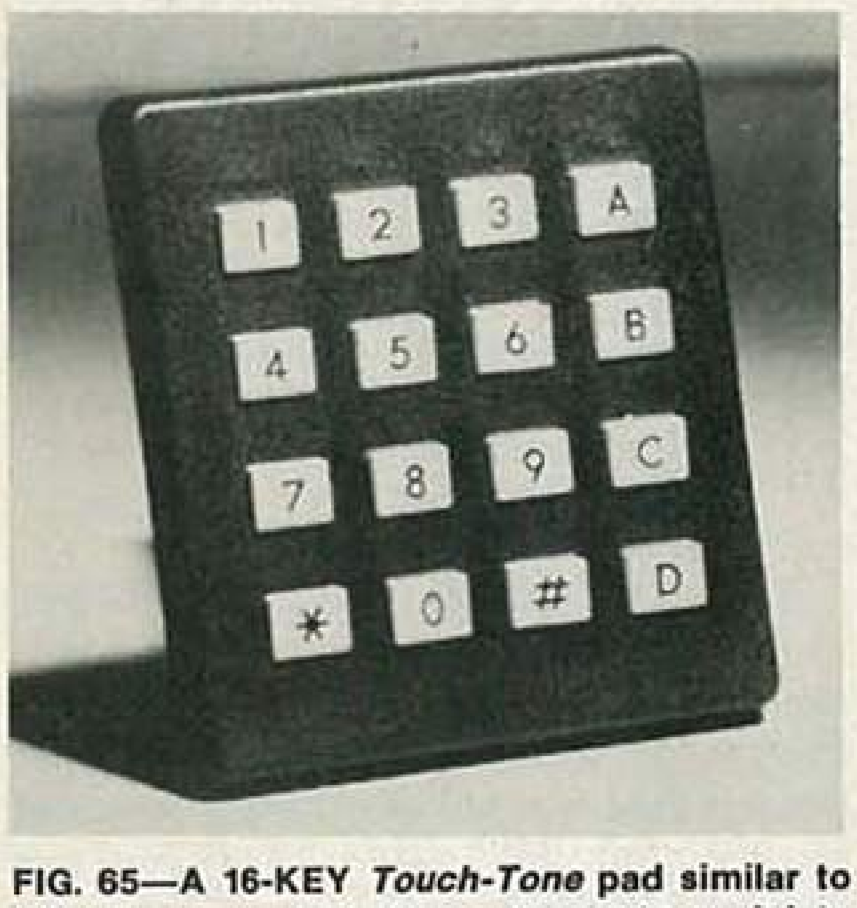


FIG. 65—A 16-KEY *Touch-Tone* pad similar to this one was used in the prototype to modulate an FM transmitter.

That tone-pair modulates an inexpensive, low-power FM transmitter operating in the FM-broadcast band. The signal is received by a standard FM broadcast-band receiver located in the robot and the tone-pairs are decoded to generate a one-out-of-sixteen control signal. That control signal is fed to a relay-driver board to energize the coils of the appropriate relays (as described in Part 7 of this series) and operate the robot's motors and solenoids.

This method will lend itself particularly well to computer control. The 16-key pad is arranged as a 4-row by 4-column switch matrix where each row generates its own tone, as does each column. The result, if the rows and columns are considered together (lined up in one row) is the equivalent of a computer *byte*—the standard 8-bit word.

A computer can output, through a parallel port, an eight-bit binary number that can represent those same switch closures. That byte can be used in place of the keypad to cause the tones to be generated, thus allowing a computer program to direct the robot's actions.

Alternatively, if the robot carries an on-board computer, the output of its parallel port can easily be translated into control signals for the relays.

Several installments will be required to describe the control system in detail. This one will talk about FM transmitters and the relay-driver board. The next will talk about the *Touch-Tone* encoding and decoding circuits, and their interfacing to the others.

Finally, we'll talk about computer interfacing and a little about programming as it pertains to robot control.

FM transmitter

This transmitter can actually be used for two purposes, although not simultaneously. In essence, it is what's commonly called an FM wireless mike. Usually it is used to transmit voices or music on an unused frequency of the FM broadcast band for personal entertainment purposes.

In that mode, using the robot's built-in amplifier and speaker (see Part 5), the robot can talk to persons in its vicinity—with a little help from the operator. In fact, if the robot carries a second wireless mike, operating on a different frequency, a two-way conversation can be carried out.

However, that is secondary to our main purpose—actually controlling the robot. (Come to think of it, though, the control tones could also be fed to the robot's amp and speaker, making him sound a little like good old *R2-D2*.)

A schematic for a wireless mike is shown in Fig. 66. No foil pattern is given, since the circuit can be easily constructed on perforated construction board. Suitable FM transmitters are also available from a number of companies who advertise in **Radio-Electronics.**

Transmitter construction

If you build your own transmitter, it can be constructed on a piece of perfo-

PARTS LIST—FM TRANSMITTER

All resistors ¼ watt, 5%
R1, R2—1 megohm
R3, R6, R9—8200 ohms
R4—330 ohms
R5—470,000 ohms
R8, R11—15,000 ohms
R12—3900 ohms
R13—220 ohms
R14 (optional)—390,000 ohms
Capacitors
C1, C3, C4, C6—5 µF, tantalum
C2—0.1 µF, ceramic disc
C5—10 µF, tantalum
C7, C11—0.01 µF, ceramic disc
C9—5-15 pF, variable (E.F. Johnson 274-0035-005 or equivalent)
C10—7 pF (approx.), ceramic disc
L1—see text
L2—see text
Miscellaneous: construction board, high-impedance microphone, solder, wire, etc.

ic, and most of the ones available as kits, are intended to be modulated by a high-impedance microphone. (If you intend to use a crystal mike, be sure to include resistor R14.)

If you are going to use the transmitter only with the *Touch-Tone* pad for control purposes, the first two stages—Q1 and Q2—can be omitted, and the output of the tone-generator IC applied to the base of Q3, since its output level is much higher than that of a microphone, and not as much amplification is needed. In fact, you probably will have to add several hundred kilohms of resistance to attenuate the tones so they do not overdrive the transmitter and cause distortion.

Best results with the homebrew transmitter were obtained when tantalum capacitors were used where values of five and ten µF were needed. The tuning capacitor, C9, should have a value such that, when it is parallelled with C10, the total capacitance does not exceed 22 pF. A good place to look for something to use as C9 is in a junked portable FM radio.

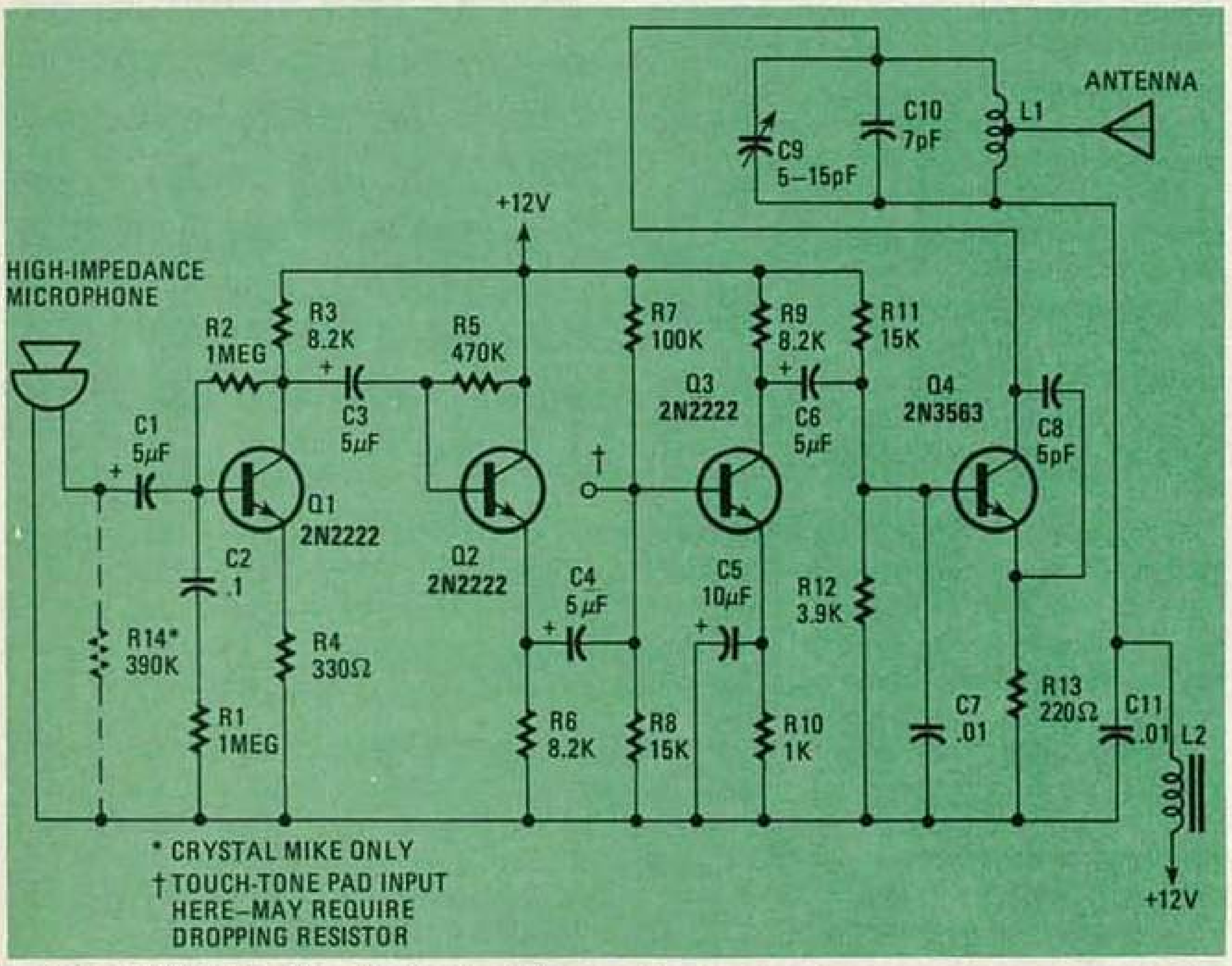


FIG. 66—SCHEMATIC DIAGRAM for the FM transmitter. Value of dropping resistor R14 may range from several hundred kilohms to two megohms or more.

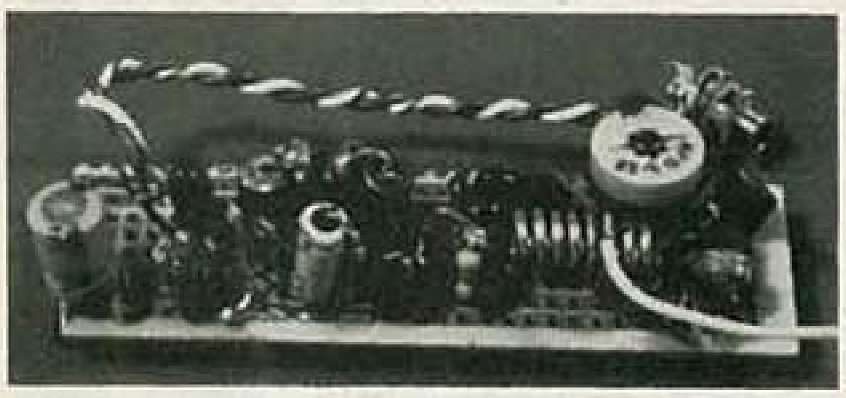


FIG. 67—PROTOTYPE TRANSMITTER built on a small piece of board. Any construction technique may be used.

rated construction board or on a prototyping board. A prototype transmitter, built on a piece of board about 1 × 4 inches, is shown in Fig. 67. Wire-wrap or point-to-point wiring techniques can be used. Keep the leads as short as possible—lead length begins to get critical at these frequencies (80-108 MHz).

The transmitter shown in the schematic, and most of the ones available as kits, are intended to be modulated by a high-impedance microphone.

Coil L1 is made using eight turns of No. 16 copper wire. Its outside diameter is ¼-inch and the total length of the coil is 0.6 inches. Coil L2 consists of 12 turns of No. 30 wire (wire-wrap wire will do nicely) closely wound around a quarter-watt resistor of the highest value you have on hand (it should be at least 100K). The ends of that coil can be soldered to the resistor leads, which, of course, then become the leads of the coil.

The antenna lead is soldered to the third turn of L1, counting from the 12-volt end of the coil. The antenna itself can be either a fancy telescoping type, or simply a piece of stiff wire. Since we are deliberately *not* trying to obtain maximum efficiency, the length of the antenna is not critical—about ten inches seems to work well.

Locate the antenna right at the transmitter, which can be mounted inside the command console if you like. It is not necessary to feed the antenna with coaxial cable—it can be connected directly to the output of the transmitter. What is important, though, is that the antenna be insulated from the case containing the transmitter, if that case is metallic, to prevent it from shorting out to ground.

The frequency of the transmitter can be affected by the antenna. It should be as rigid as possible and, more important, because of capacitance effects, it should be as far away from possible contact with your body as possible. Keep that in mind when you are tuning the transmitter, especially if the transmitter and antenna are mounted on the case containing the keypad and tone encoder.

The best section of the FM band for your use is probably the bottom—around 88 MHz. Tune your receiver to a clear spot in that area and turn up the volume so you can hear some background hiss. Then, using an insulated—or plastic—screwdriver, *slowly* adjust C9, or its equivalent, if you assembled a kit, until the hiss is blanked out. That will indicate that you are receiving your transmitter's carrier. Be patient—the tuning process is critical. It may also be necessary for you to stretch or compress L1 slightly to get into the right portion of the band.Before you fire up the transmitter, you should be aware of the FCC regulations governing the use of such devices. Those regulations may be summarized as follows:

- The use of such devices for personal surveillance is illegal!
- The range of such devices is limited to 100 feet. Do not attempt to extend that range through the use of higher power or more efficient antenna systems—use only what you need! Improve your *receiver,* if necessary.
- Do not attempt to use the transmitter below 88 MHz or above 108 MHz. The former may interfere with commercial two-way radio services; the latter with aircraft communications. Do not use the transmitter anywhere near commercial airlanes!

To be safe, make sure the signal begins to fade out about 90 feet from the transmitter. If it is too strong at that range, shorten the antenna or reduce the input power. That will not only keep you out of trouble, but will ensure that you can clearly observe—and control—the robot's actions before it does something to embarrass you.*

In the next part of this series we'll go into detail on connecting the tone genera-

*Due to the difficulty in obtaining positronic brains, Isaac Asimov's Three Laws of Robotics do not apply here, and we have to use our own judgment, rather than rely on the robot's.

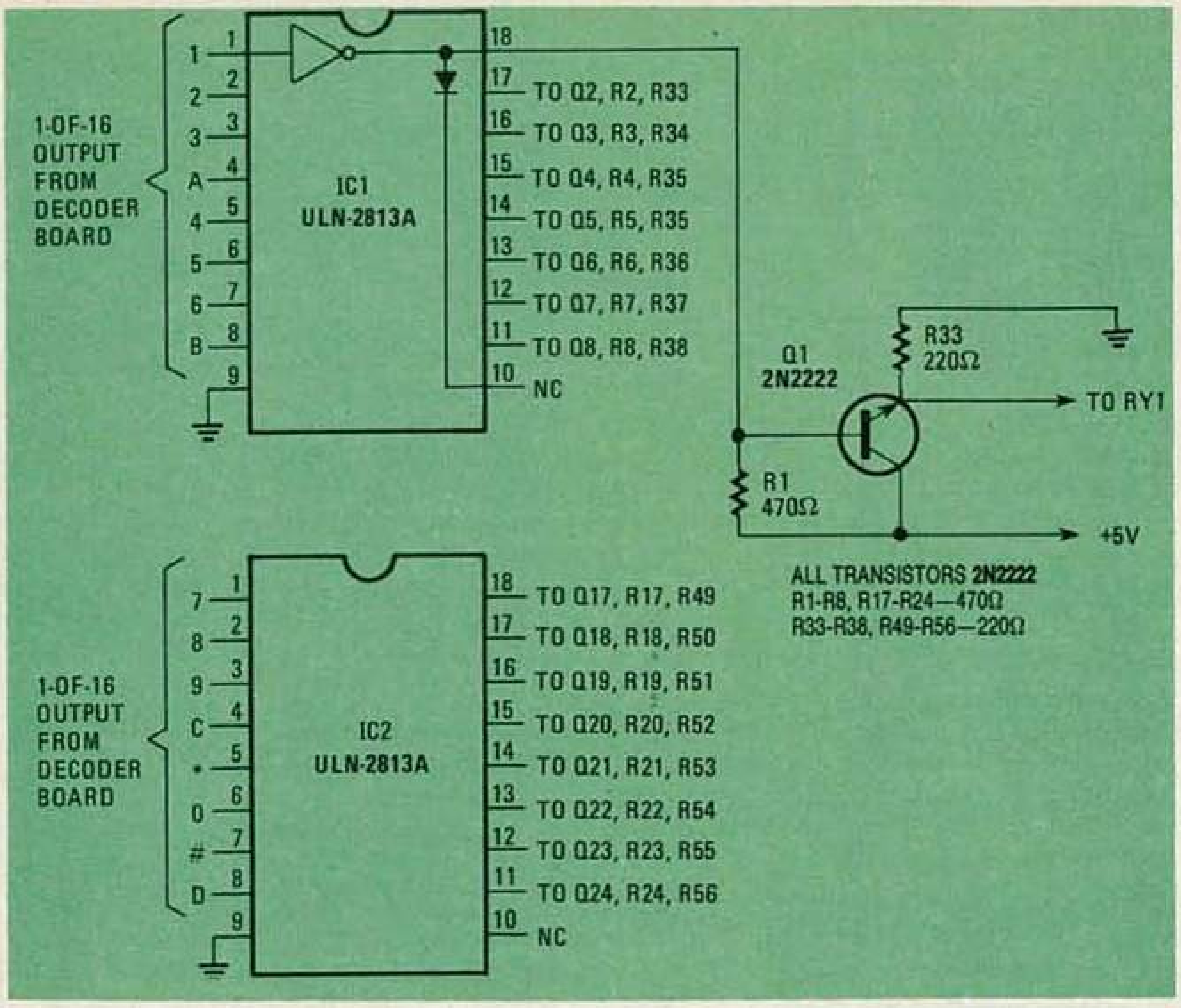


FIG. 68—SIMPLIFIED SCHEMATIC of the relay-driver board. Only one section is shown as all others are the same.

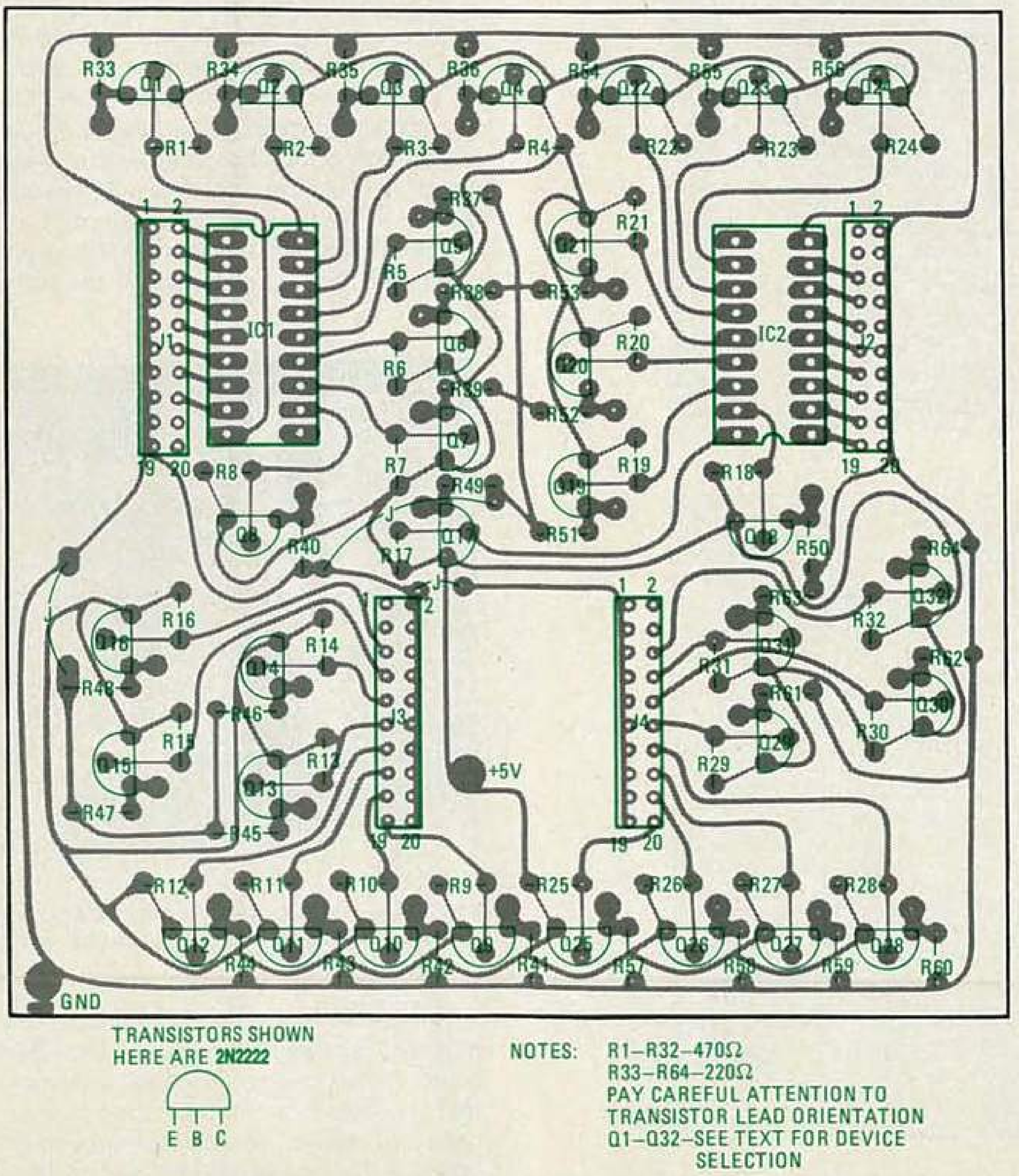


FIG. 70—PARTS PLACEMENT diagram for the relay-driver board. If 2N2222 transistors are not handy, almost any other type may be used.

tor to the transmitter, and the tone decoder to the receiver (and to the robot).

Relay-driver board

A portion of the relay-driver board circuit is shown in Fig. 68. There is really very little more to it than that—the same circuit, for all intents and purposes, is repeated 32 times.

A foil pattern for the relay-driver board is shown in Fig. 69, and the parts-placement diagram in Fig. 70. Don't be put off by its complexity, though. Initially, we'll use only half of that board—each relay will have its own output from the ULN-2813A driver IC and its own transistor. The balance of the board is reserved for future use—primarily when it becomes necessary for the robot, when it gets its on-board computer, to respond to stimuli from its environment. It can also serve to provide other control functions if a more sophisticated control system is used, and suggestions for that will appear in a future part of this series.

Jacks J1 and J2 will be used to connect the relay-driver board to the decoder board.

Here's how the circuit works: The ULN-2813A is an inverting octal driver. What that means is that it has eight identical sections; and when a logic-high signal (about five volts) from the decoder board is applied to the input of one of the sections, the output of that section goes to a logic-low state (zero volts, or ground) and will act as a ground for any voltage that is applied to it.

When an output of the IC goes "low," it causes its associated transistor to be saturated. That allows five volts to pass from the collector and out the emitter to the coil of the relay assigned to that transistor, causing the relay contacts to close. That's all there is to it.

Although IC pin and function assignments are arbitrary, Table 1 shows a suggested arrangement for use with a 16-key *Touch-Tone* keypad.

Because we are limited to 16 on/off control signals, several of the robot's original functions temporarily have had to be eliminated or combined. For example, we can no longer beep the horn, and both end-effectors now operate simultaneously.

Regaining those lost functions will be easy under computer control and later we'll present a couple of ideas for some simple logic circuits that will allow the 16 radio-control channels to provide more than 16 functions.

Construction of the board is straightforward. The 2N2222 transistors were used because they were handy. As Fig. 71 shows, almost any transistor can be used—you can see four different types there. If you have PNP—say, 2N2907—instead of NPN transistors, the only change that has to be made is to insert the transistors in the board backwards—the emitter goes where the collector would

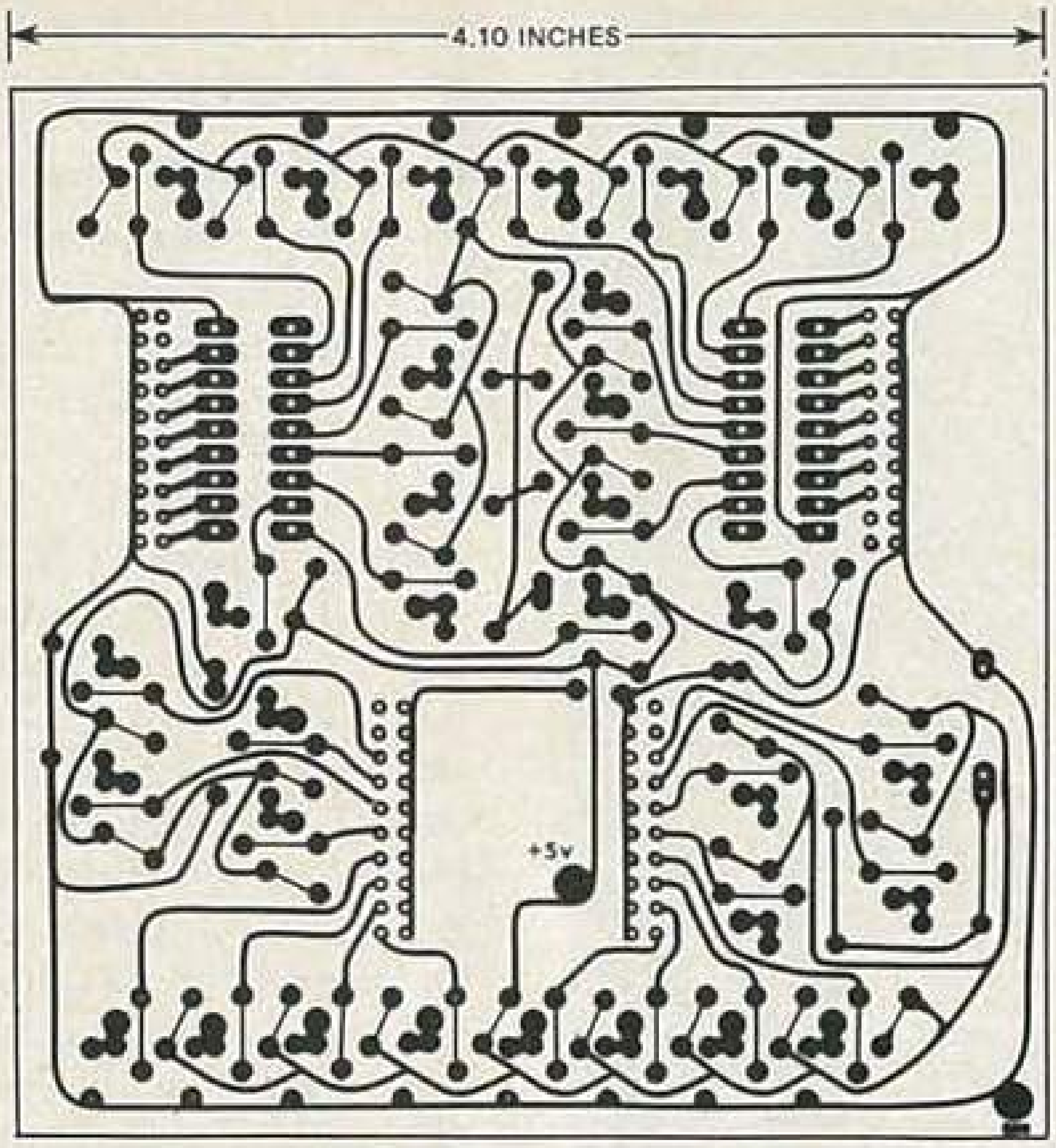


FIG. 69—FOIL PATTERN for the relay-driver board. Only half the board will be used at this time, with the rest reserved for expansion.

TABLE 1		
IC No., Pin No.	**Key No.**	**Function**
IC1, 1	1	Both wheels, forward
″ , 2	2	Both wheels, reverse
″ , 3	3	Left wheel, forward
″ , 4	A	Left wheel, reverse
″ , 5	4	Right wheel, forward
″ , 6	5	Left & right arm solenoids
″ , 7	6	Body rotate, right
″ , 8	B	Body rotate, left
IC2, 1	7	Left shoulder, up
″ , 2	8	Left shoulder, down
″ , 3	9	Right shoulder, up
″ , 4	C	Right shoulder, down
″ , 5	*	Left arm, up
″ , 6	0	Left arm, down
″ , 7	#	Right arm, up
″ , 8	D	Right arm, down

TABLE 2		
Transistor	**Relay No.**	**Finger No.**
Q1	RY3, RY5	R, 6
Q2	RY4, RY6	M, 3
Q3	RY3	R
Q4	RY4	M
Q5	RY5	6
Q6	RY19, RY20	18, 4
Q7	RY1	20
Q8	RY2	17
Q17	RY9	P
Q18	RY10	L
Q19	RY11	7
Q20	RY12	2
Q21	RY15	N
Q22	RY16	8
Q23	RY17	5
Q24	RY18	1

PARTS LIST—RELAY-DRIVER BOARD

All resistors ¼ watt, 5%
R1-R32—470 ohms
R33-R64—220 ohms
Semiconductors
IC1, IC2—ULN-2813A inverting octal driver (Sprague)
Q1-Q32—2N2222 or equivalent NPN-type; 2N2907 or equivalent PNP-type (see text for details)
J1, J2—20-pin, double row, header connector (AP Products AP923862-R or equivalent)
Miscellaneous: PC board, 22/44-finger prototyping board (Radio Shack 276-154 or equivalent), two 22/44-pin sockets (Radio Shack 276-1551 or equivalent), 18-pin IC sockets, mating connectors for J1 and J2, 20-conductor ribbon cable, hardware, wire, etc.
A PC board for the relay driver board is available from PPG Electronics Co., Inc, 14663 Lanark St., Van Nuys, CA 91402. (213) 988-3525. Price is $9.95 plus $1.00 for shipping and handling. CA residents add 6% tax. MC and Visa accepted.

be, and vice-versa. The resistor placement can stay as shown.

Installation

After the relay-driver board has been completed, it is piggy-backed onto a 22/44-finger board like the one that was used for the relay board, using ¼-inch spacers. Make positively sure that the two boards are electrically isolated from each other.

The emitter (output) of each 2N2222 transistor is connected to a finger on the piggy-back board. You can use wire-wrap wire for that. The most straightforward way is to use the same finger number (or letter) as that which is connected to pin 16 of the appropriate relay on the relay board (See Table 2).

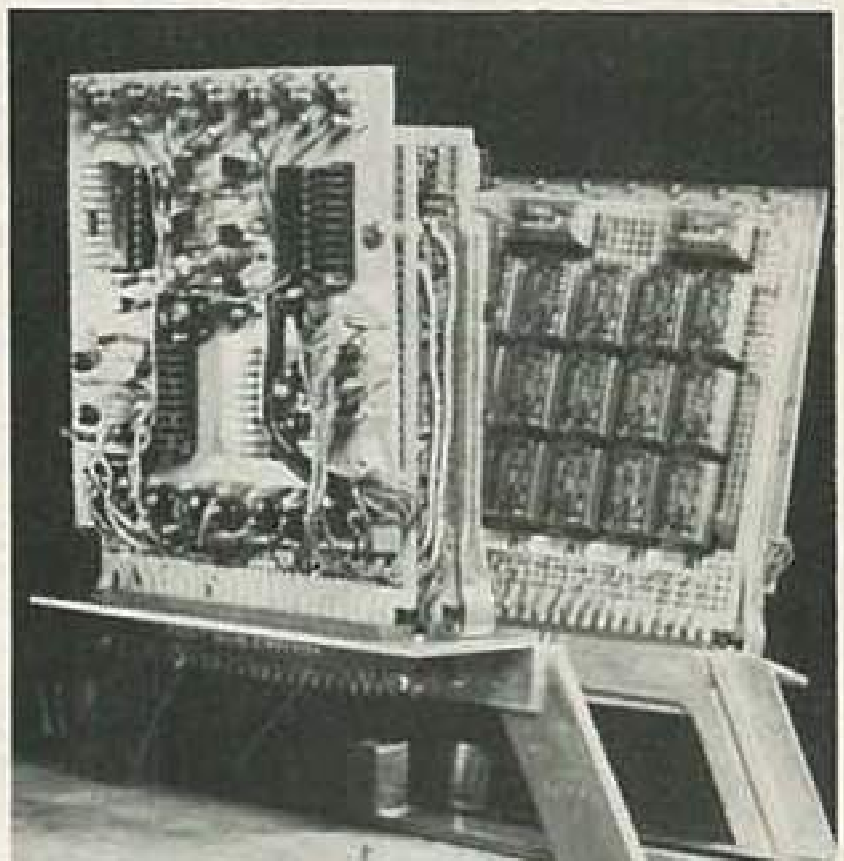


FIG. 71—THE RELAY-DRIVER BOARD is mounted parallel to the relay board, seen reflected in the mirror.

A 22/44-pin edge connector is mounted parallel to the one for the relay board (refer to Fig. 71) and, assuming that you have followed the wiring scheme described above, connections are made between like-numbered pins on the driver-board socket and the relay-board sock-

continued on page 82

RADIO PRODUCTS

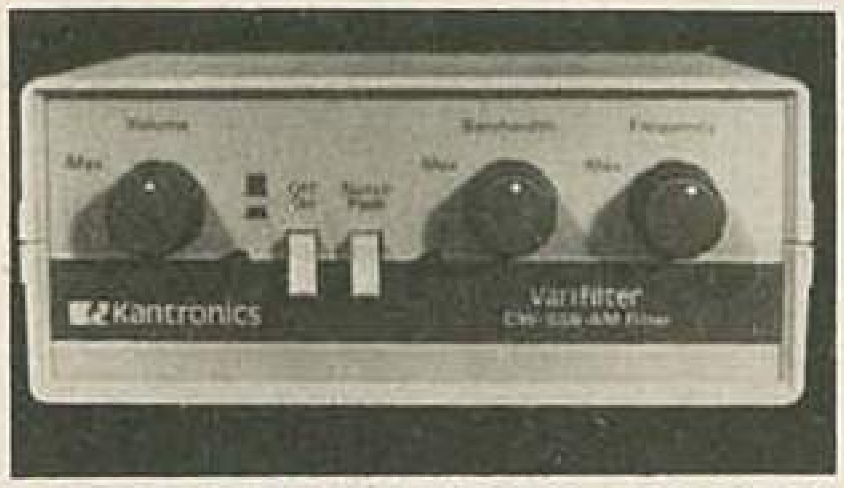
continued from page 80

of three coaxial antenna outputs, one long-wire antenna, and one coaxial tuner bypass. The impedance is 10-300 ohms. A direct-reading SWR meter on the front panel is calibrated from 1.1 to infinity.

The front-panel power meter displays RMS power with continuous (CW) carrier and automatically displays the peak power when in the SSB mode in ranges of 0-250 W and 0-2500 W.

The price of the *model AT2500* is $698.00. **—Bell Industries,** J. W. Miller Division, 19070 Reyes Ave., P.O. Box 5825, Compton, CA 90224.

VARIABLE FILTER, the *Varifilter* can be set to maximize one signal (peaking) or to minimize an interfering signal (notching); it works with CW (Morse), single-sideband, and AM signals, without ringing, oscillation, or instability. The bandwidth is variable from under 30 Hz to over 1 kHz.



CIRCLE 126 ON FREE INFORMATION CARD

The *Varifilter* has its own internal power supply, which is switchable from 115 to 230 VAC, and can also run from 12 to 18 VDC. Each unit has a tuning eye that lets the operator see when he has filtered the signal he wants to.

The *Varifilter* is priced at $139.95.**—Kantronics,** 1202 E. 23rd Street, Lawrence, KS 66044.

UNICORN-

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et. Table 2 will also help you with that.

Because it is possible to insert the boards into the sockets backwards, we recommend that you use a marker pen or nail polish to indicate the finger-1 edge of the board and the pin-1 end of the socket. If the boards are removed and then replaced, lining up the marks will prevent embarrassing accidents.

Things to come

Because the radio/computer-control section of the robot involves so many parts, it is impossible to present everything in one section and make the transition from a cable-controlled robot to a radio-controlled one in a single jump.

The circuit described here, though, can be checked out by disconnecting the switches in the command console from the 12-volt supply, and providing them with five volts, instead. The motor and solenoid wiring inside the robot, which has served us well, can now be connected to the relays via the pins on the relay-board socket. Refer to Tables 1 and 3 in Part 7. The five-volts from the command-console switches can now be supplied, via the existing umbilical cable.

Next month we'll present the radio-control tone-encoding and decoding circuits, and Unicorn-1 will be able to cut its apron strings. R-E

UNICORN-1 ROBOT

Part 9—This installment of the Unicorn-1 series finishes equipping the robot for remote-control operation with tone-encoder, tone-decoder and latch boards.

JAMES A. GUPTON, JR.

TO COMPLETE CONVERTING YOUR ROBOT to radio control, using the method outlined previously, three more circuits have to be added. They are: a *Touch-Tone encoder board,* a *decoder board,* and a *latch board.* Those, together with the boards constructed earlier, will allow the robot to be controlled remotely.

Encoder board

The *Touch-Tone* encoder board is designed for use with a 16-key *Touch-Tone* keypad. In addition to the numbers zero through nine and the "#" and "*" signs, that pad also has keys labeled "A" through "D."

The keys are arranged in an array of four rows by four columns. Each row and column has a particular tone frequency assigned to it, as shown in Table 1. Pressing any key causes a unique tone pair to be generated. Those tone pairs are generated by the encoder board, whose schematic is shown in Fig. 72.

The encoder IC, a 7206JPE, is designed to take a "row" input and a "column" input and to output the appropriate tone pair, deriving those tones by dividing down the output of a 3.579545-MHz TV color-burst crystal. The tone pair appears at pin 15 of the IC.

An LED is included in the circuit to indicate visually that tones are being generated. Similarly, Q1, a medium-gain NPN transistor, can be used to drive a speaker so the tones can be heard. The speaker can be eliminated if desired, or, as shown in the schematic, you can insert a resistor in the circuit to reduce the volume of the audio output.

The signal fed to the FM transmitter described in the previous part of this series is taken from the base of Q1. A dropping resistor (whose value may range from several hundred kilohms to several megohms) may be necessary between this point and the transmitter input to avoid overdriving the transmitter.

A 9-volt battery operates the encoder very nicely. If the encoder and transmitter are packaged together, use a separate battery for each one.

The foil pattern for the small, single-sided, encoder board is in Fig. 73. Component placement is in Fig. 74.

TABLE 1

ROW	1	697 Hz
"	2	770 Hz
"	3	852 Hz
"	4	941 Hz
COLUMN	1	1209 Hz
"	2	1336 Hz
"	3	1477 Hz
"	4	1633 Hz

Decoder board

The transmitted tones are picked up at the robot-end of the radio link by a standard portable FM receiver. It can be mounted inside the robot's body with a whip antenna mounted externally.

Output to drive the decoder board can be taken from the radio's earphone jack or, if you want the tones to be heard coming from the robot, from the speaker terminals. The audio can also be fed to the robot's on-board amplifier. Again, a dropping resistor may be required.

Figure 75 is the schematic of the decoder. The tone pair is fed to resistor R9, the level control, and from there to eight 567 PLL tone-decoders. Each 567 is set to respond to one of the eight tones that can be produced by the encoder board. Each tone pair causes the output lines (pin 8) of *two* of the 567's—one for each of the two tones—to go to a logic-low state.

Those outputs are NOR'd by IC9 through IC12, producing a logic-high at the IC output-pin corresponding to the key pressed.

Because of its complexity, that circuit is designed around a double-sided PC board. Figure 76 shows the "foil" side of the pattern, while Fig. 77 shows the pattern for the "component" side of the board. (For those who do not have the facilities to make double-sided boards, sources have been provided—see the note at the end of the parts list.) Parts placement is shown in Fig. 78 and an assembled board in Fig. 79.

The board requires a well-regulated

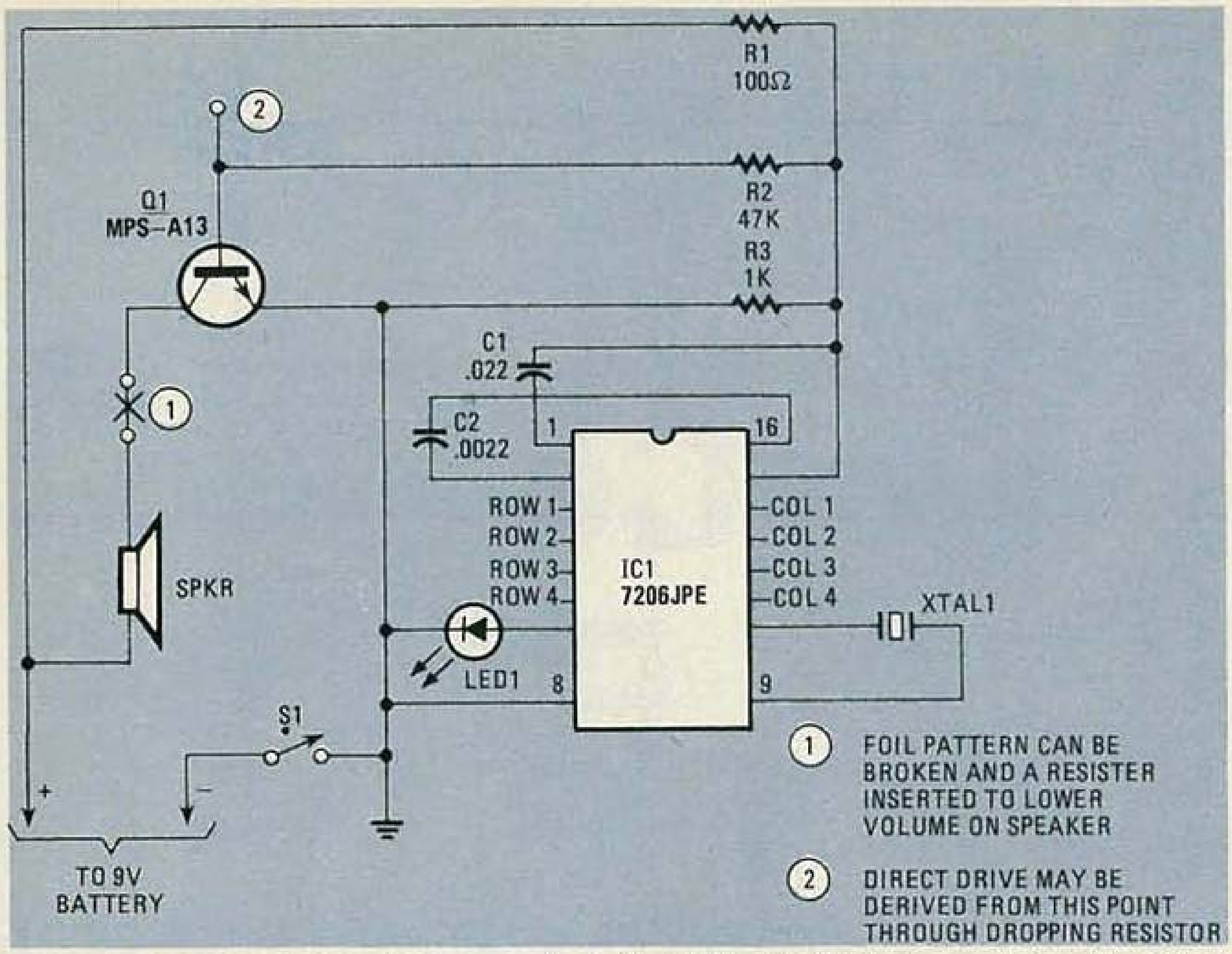


FIG. 72—HEART OF THE *Touch-Tone* encoder is the ICM7206JPE IC that converts "row" and "column" inputs into tone pairs. Speaker shown is optional.

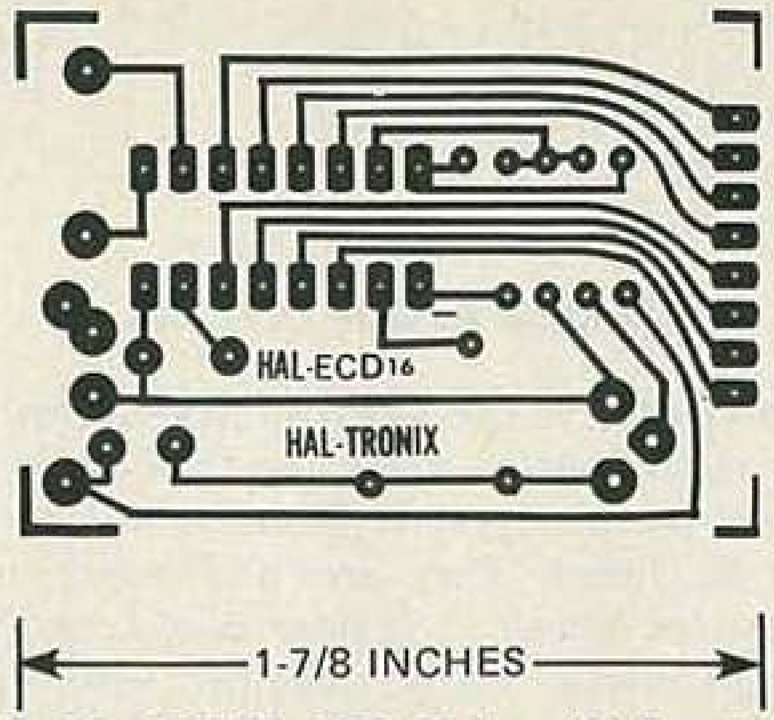


FIG. 73—ACTUAL-SIZE PC board foil pattern for *Touch-Tone* encoder. Eight pads at right are for connection to keypad.

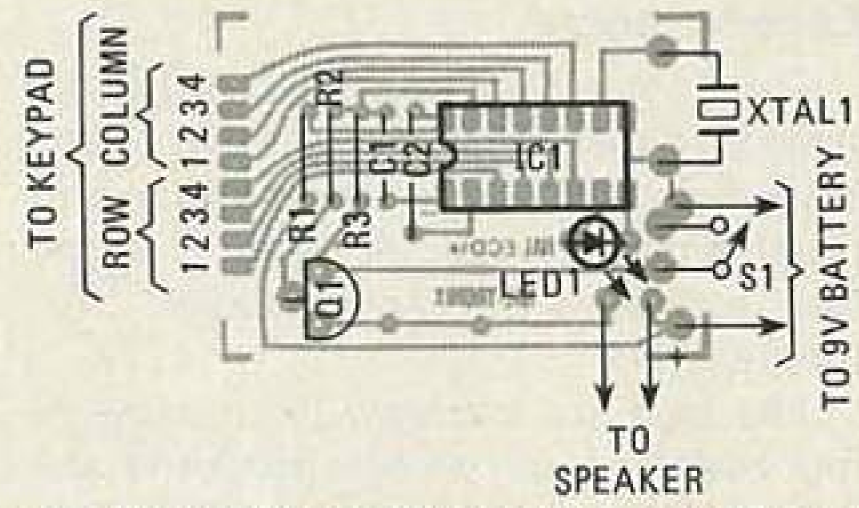


FIG. 74—WHEN CONNECTING encoder board to FM transmitter, make sure that battery polarities agree.

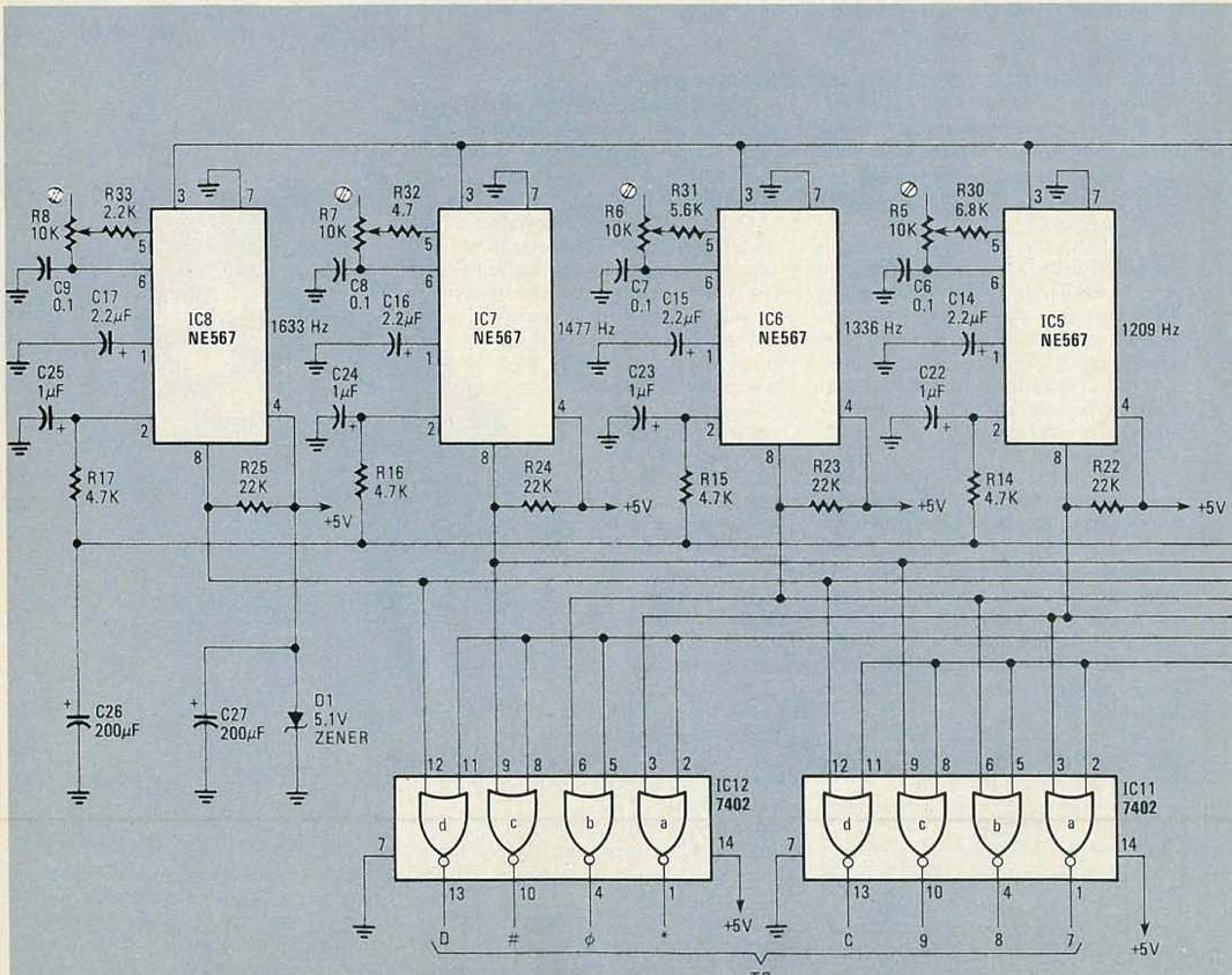
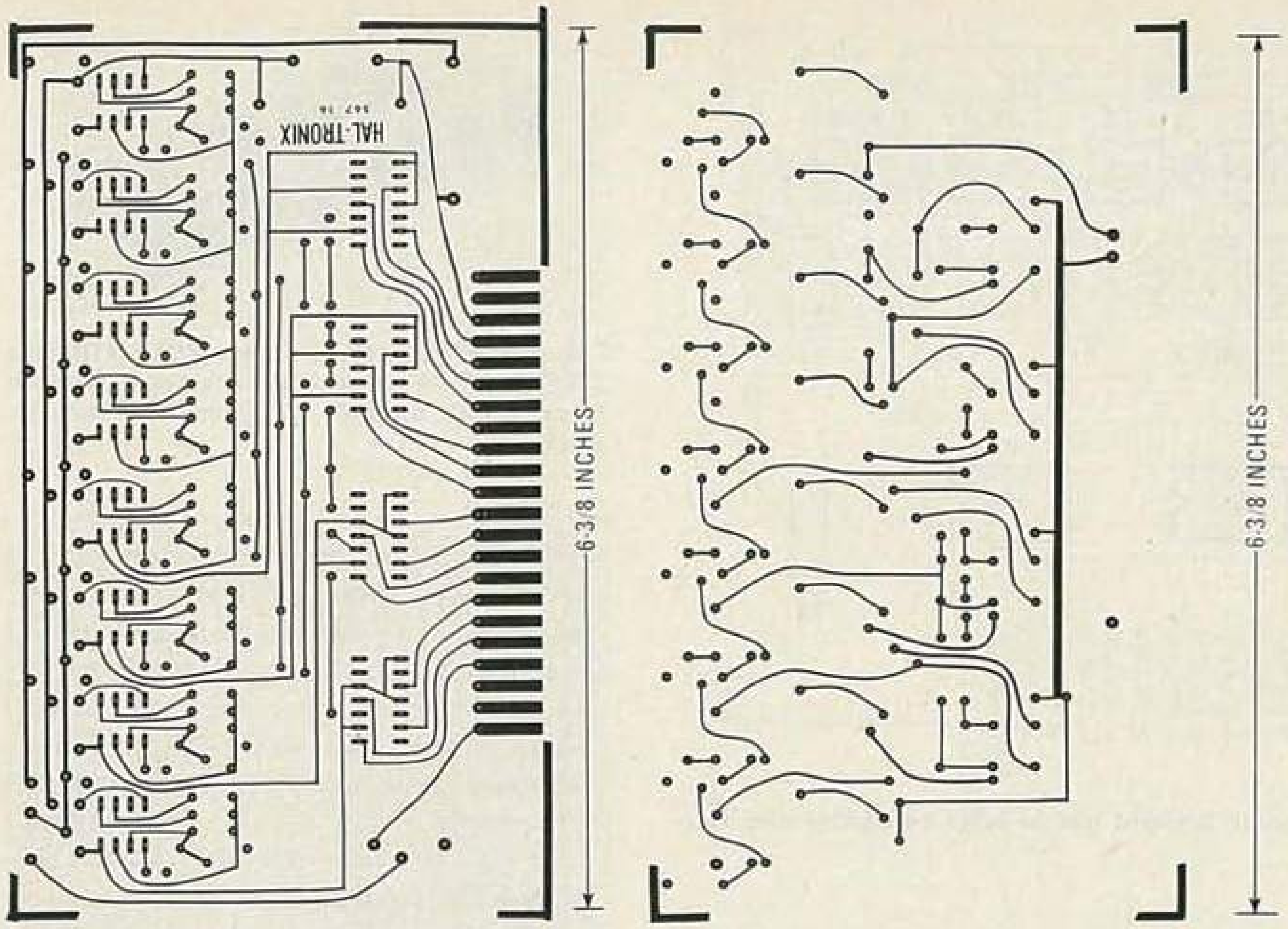


FIG. 75—TONE PAIRS are fed to all eight 576 phase-lock loop IC's on decoder board. Decoded tone pairs are NOR'd to produce a one-of-sixteen logic-"high" output.



FIGS. 76 & 77—DECODER BOARD is double-sided. Pattern at left is for bottom; pattern at right for top (component side). If you make your own board, holes that go to foil traces on both sides must either be plated through, or jumpers run from one side of board to the other.

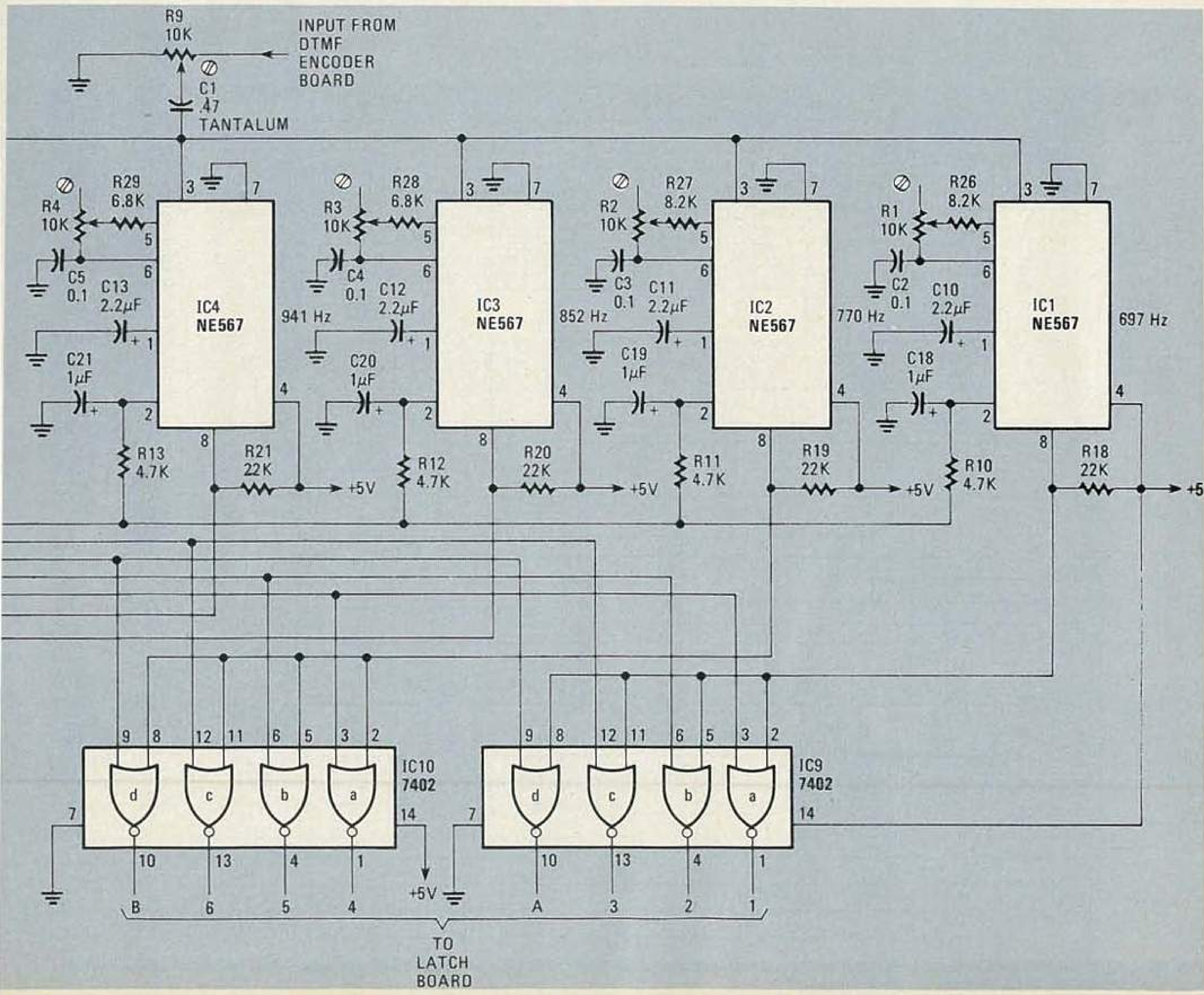
PARTS LIST—DTMF ENCODER BOARD

All resistors ¼ watt, 5%
R1—100 ohms
R2—47,000 ohms
R3—1000 ohms

Capacitors
C1—0.022 μF, ceramic disc
C2—0.0022 μF, Mylar
C3—39 μF, tantalum

Semiconductors
IC1—7206JPE DTMF tone generator
Q1—MPSA-13 or equivalent NPN-type
LED1—jumbo red LED
XTAL1—3.579545 MHz TV color-burst crystal
S1—SPDT push button switch

Miscellaneous: PC board, IC socket, 8-ohm speaker, 16-key keypad (Digitran KL0049 or equivalent), cabinet, battery clip, etc.



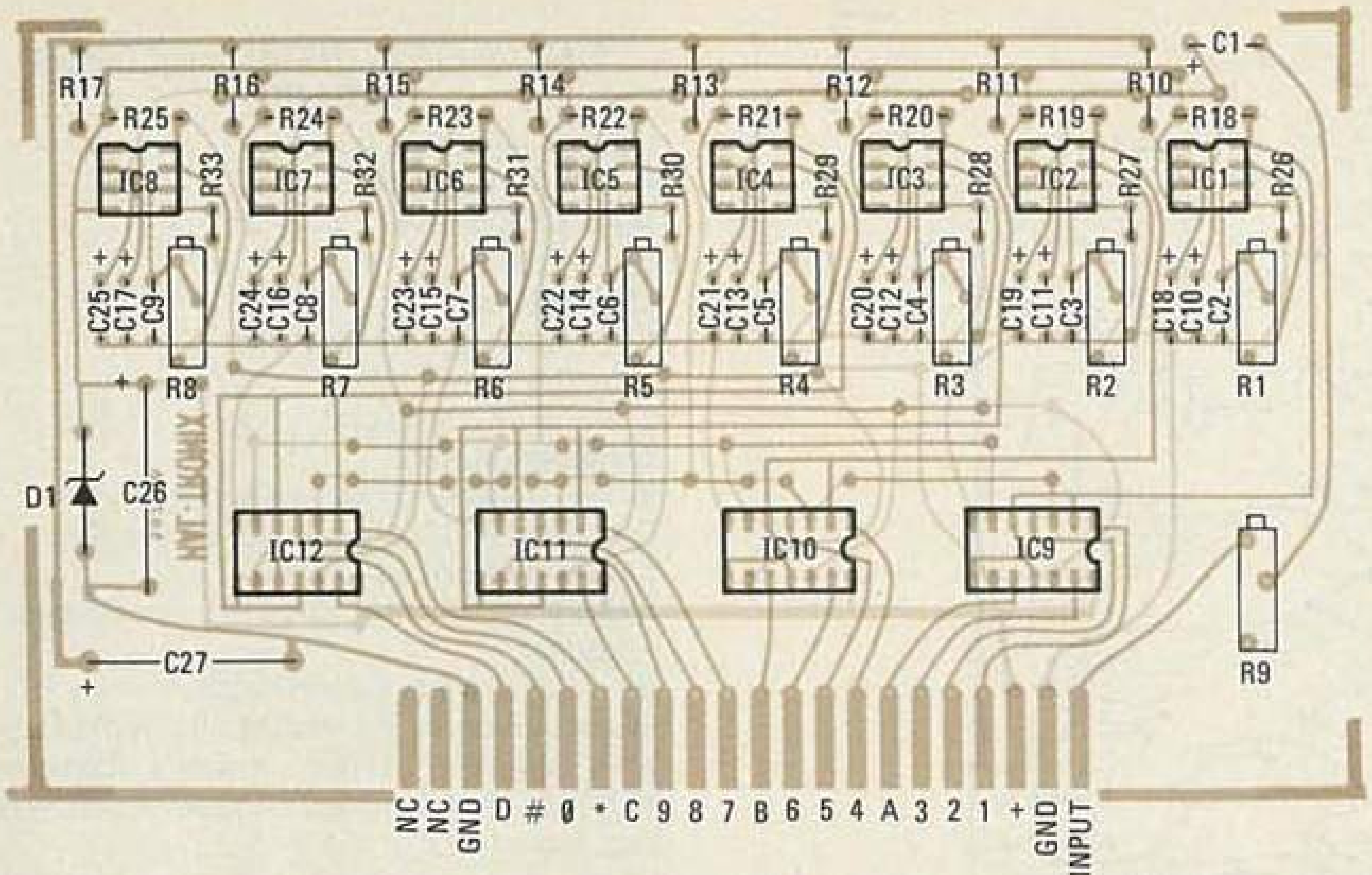


FIG. 78—THE DTMF DECODER BOARD has all signals brought out to edge connector and also available on the board itself.

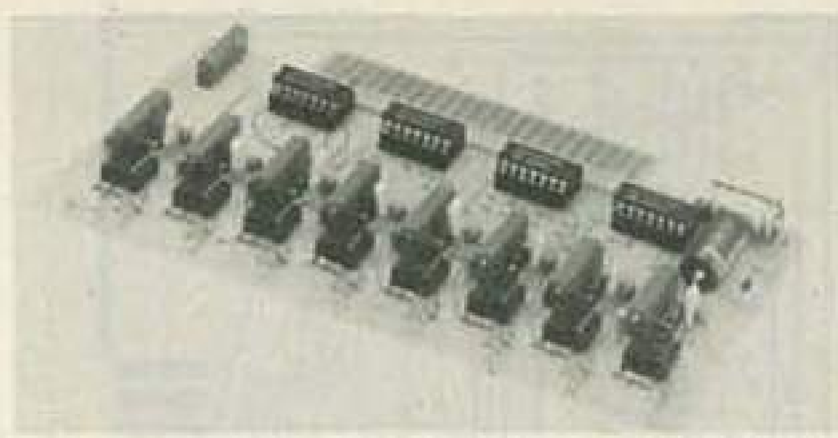


FIG. 79—WHEN MOUNTING POTENTIOMETERS make certain to allow clearance between them and IC sockets for screwdriver adjustment.

We've been receiving a lot of correspondence from readers who are building—or contemplating building—their own versions of Unicorn-1. We'd like to see more, along with nice sharp photographs, so we can publish a segment showing off those robots and presenting some of the innovations that you've come up with. Write to **Radio-Electronics,** 200 Park Avenue South, New York, NY 10003 and mark your envelope "ROBOT UPDATE."

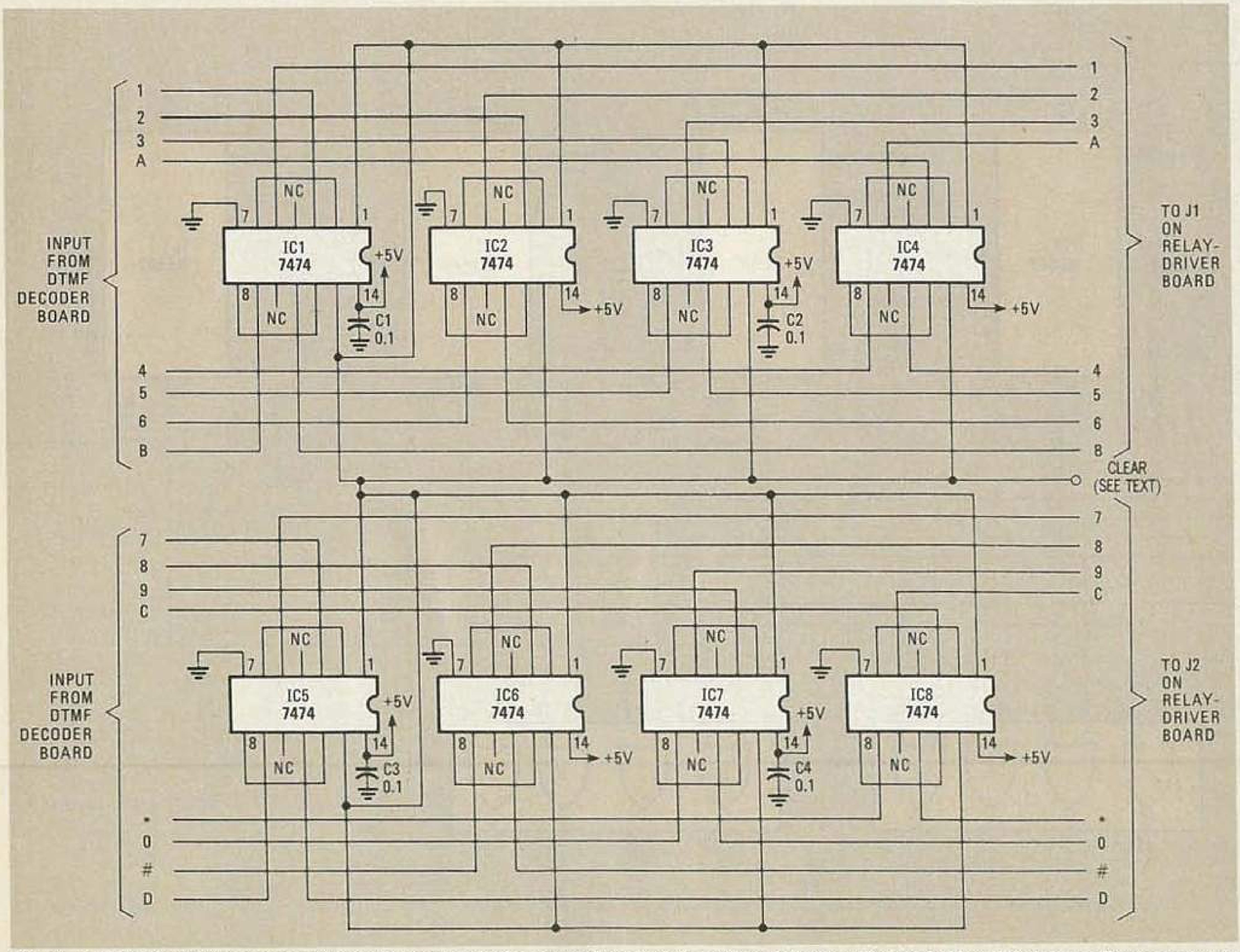


FIG. 80—LATCH BOARD takes output of decoder board and "remembers" commands until second output disables latches. This feature allows commands sent out sequentially to be carried out simultaneously.

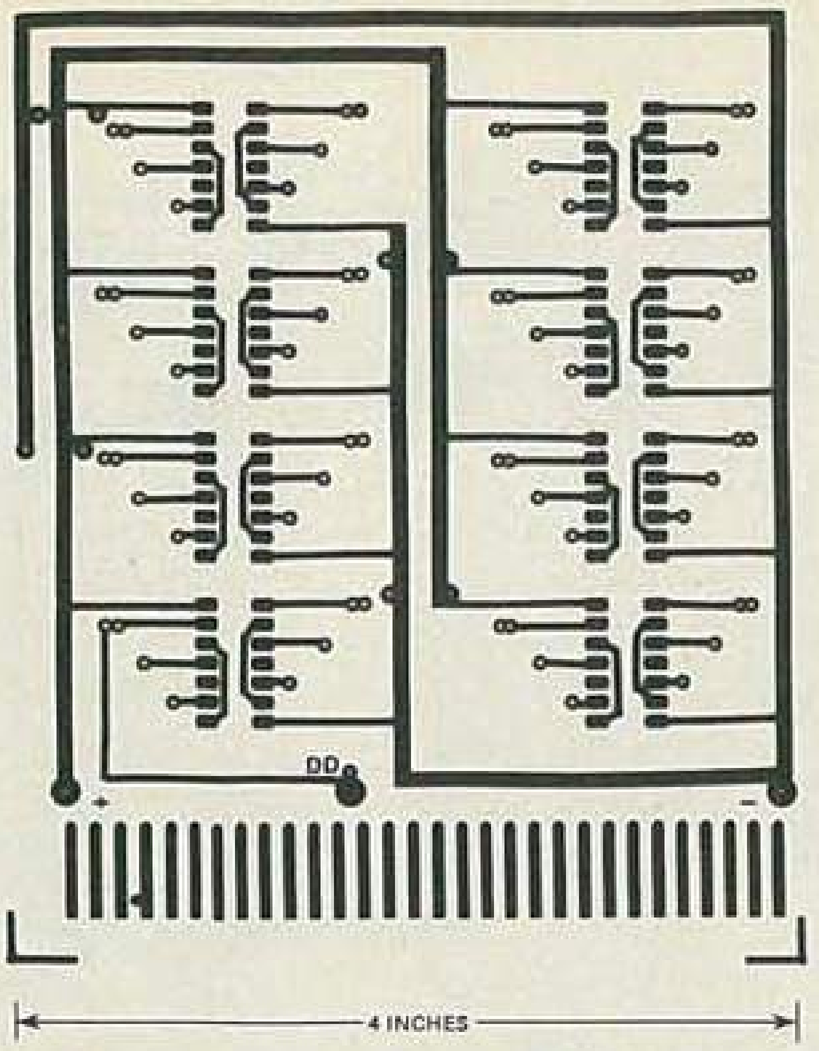


FIG. 81—IF "DROP-DEAD" feature is desired, "double-donut" pads must be jumpered together.

PARTS LIST—LATCH BOARD

Capacitors
C1-C4—0.1 μF, ceramic disc
Semiconductors
IC1-IC8—7474 dual "D" edge-triggered flip-flop
Miscellaneous: PC board, IC sockets, ribbon cable, etc.
The following are available from: Hal-Tronix, PO Box 1101, Southgate, MI 48195, Tel. (313) 285-1782: encoder kit, including case (ECD-16DL), $39.95; encoder kit less case (ECD-16K), $29.00; PC board only (ECD-16PC), $8.00. Decoder kit (no case) (567-16K), $69.95; double-sided, plated-through PC board only (567-16PC), $21.00. Latch board kit (LB-16K), $18.95; PC board only (LB-16PC), $11.95. Also available from the same source: ICM7206JPE IC, $8.95; 16-key keypad, $11.95. Please add $2.00 shipping & handling on orders under $20.00. Visa and MC accepted. Boards and kits are also available from: The Robot Mart, Room 1113, 19 W. 34th St., New York, NY 10001 (catalog $3.00).

PARTS LIST—DTMF DECODER BOARD

All resistors ¼ watt, 5% unless otherwise specified
R1-R9—10,000 ohms, ten-turn trimmer potentiometer (Bourns 3006P or equivalent)
R10-R17, R32—4700 ohms
R18-R25, R33—2200 ohms
R26, R27—8200 ohms
R28-R30—6800 ohms
R31—5600 ohms
Capacitors
C1—0.47 μF, tantalum, or ceramic disc
C2-C9—0.1 μF, Mylar or monolithic
C10-C17—2.2 μF, tantalum or aluminum electrolytic
C18-C25—1 μF, tantalum or aluminum electrolytic
C26, C27—200 μF, electrolytic
Semiconductors
IC1-IC8—NE567 PLL tone decoder
IC9-IC12—7402 quad NOR gate
D1—5.1 volts, 1 watt, Zener
Miscellaneous: double-sided, plated-through PC board, IC sockets, ribbon cable, etc.

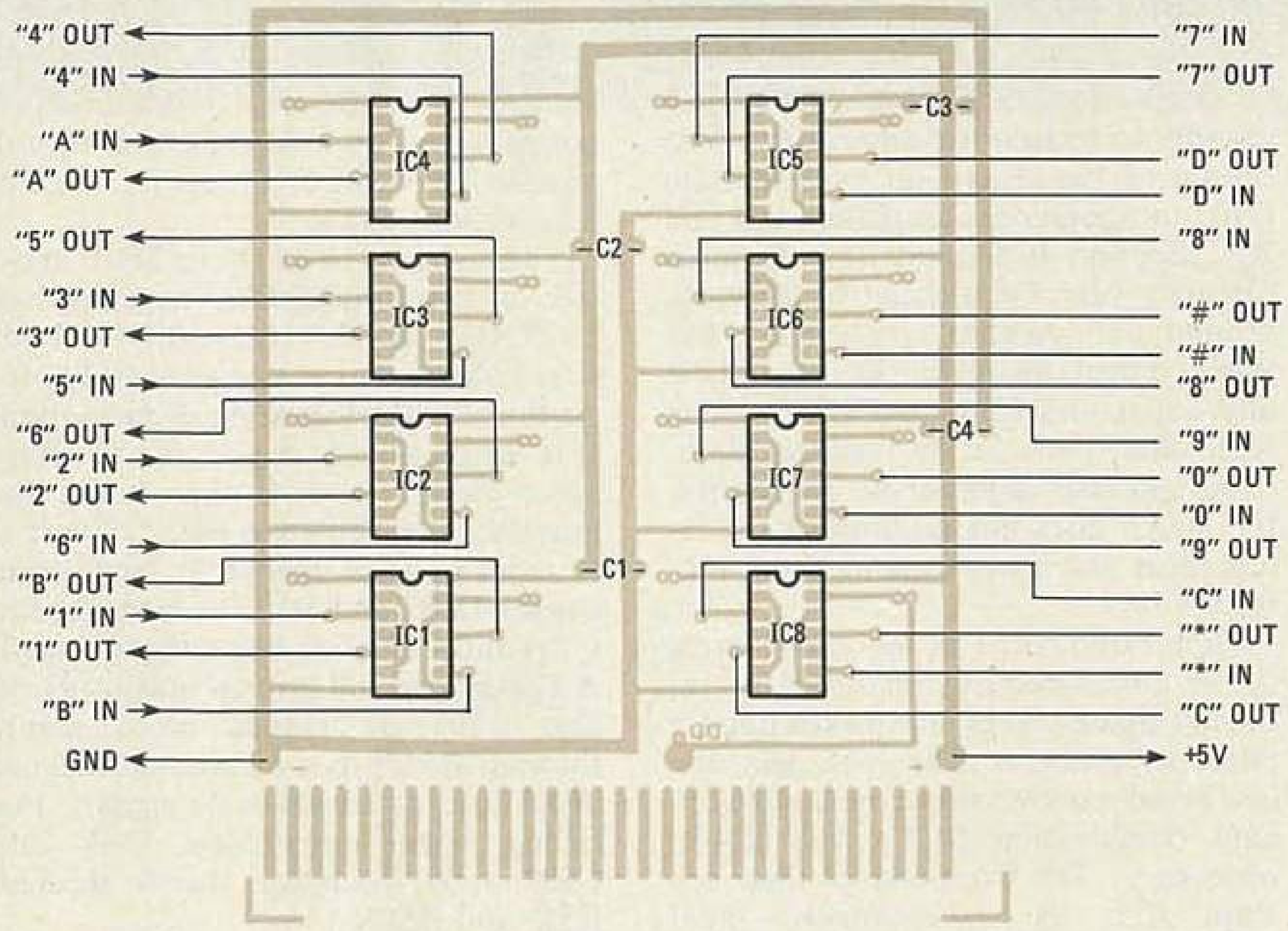


FIG. 82—LATCH BOARD SIGNALS *are not* brought out to edge connector. Connections must be made to pads on board. The use of multicolored ribbon cable is suggested.

five-volt supply to operate properly. Alignment is simple: Starting with IC1, connect a frequency counter to pin 5 of the 567 (no signal input is necessary). Adjust the 10K potentiometer associated with the IC until the frequency indicated on the schematic for that IC is obtained.

Proper tone-decoding can be verified by applying a tone pair to the input of the board and checking for a logic-high at the corresponding output pin of the 7402 NOR gates with a logic probe.

If the probe's HIGH LED does not stay on steadily, it indicates that one or both of the 567's associated with that tone pair is not quite on frequency and needs a slight adjustment. If you have to make such an adjustment, proceed carefully—remember, each 567 is responsible for *four* individual outputs and you must check them all.

Latch board

While it is possible to operate the robot without the latch board, there are two important reasons why it should be included.

Firstly, it eliminates the need to keep a function key depressed. With the latch board, the key is pressed once to initiate the function desired, and pressed again to stop it. Not only does that save wear and tear on the batteries (and fingers) but it also brings us to the other reason for using the latch board.

Without it, only one function at a time could be carried out by the robot. With it, however, as many functions as desired can be operated at the same time and they can be switched on and off at will.

The latch board (Fig. 80) uses eight 7474 dual D, edge-triggered, flip-flop IC's to form 16 latches. The latching action is handled by cross-coupling each gate's inverting output (pin 6 or 8) to the "D" input (pin 2 or 12) of the IC. The status of the "D" input determines the status of the outputs. If it is "high," the normal (non-inverting) output (pin 5 or 9) is also "high," and the inverting output is "low." If it is "low," the status of the outputs is reversed.

The 7474 triggers on a "low" to "high" transition of the input (clock) signal (pin 3 or 11). When a signal from the decoder board is applied, a "high" to "low" transition takes place and the normal (non-inverting) output of the gate goes "high" and stays "high." Simultaneously, the inverting output goes "low." That forces the "D" input "low," which means that the next "high" to "low" transition at the input will cause the output to go "low," and so on.

That means that the first time a function key is pressed, a function will be called into play. The next time it is pressed, that function will stop. And since, once the latch has been set, the function continues, another key can be pressed and another function called up while the first is running.

The CLEAR inputs of the IC's (pins 1 and 13) are also brought out to the board (the double donut pads in Fig. 81—if used they should be jumpered together) for future use. If the CLEAR inputs are grounded, the latches immediately go to a "low" state. That feature can be used as a "drop dead" switch to completely disable the robot by pushing a single key, if it becomes necessary.

The "drop dead" feature could also be

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UNICORN-1 ROBOT
continued from page 69

tied into the FM receiver. Now, if the carrier from the transmitter were lost, the robot would immediately stop functioning—a nice safety feature for long-range work.

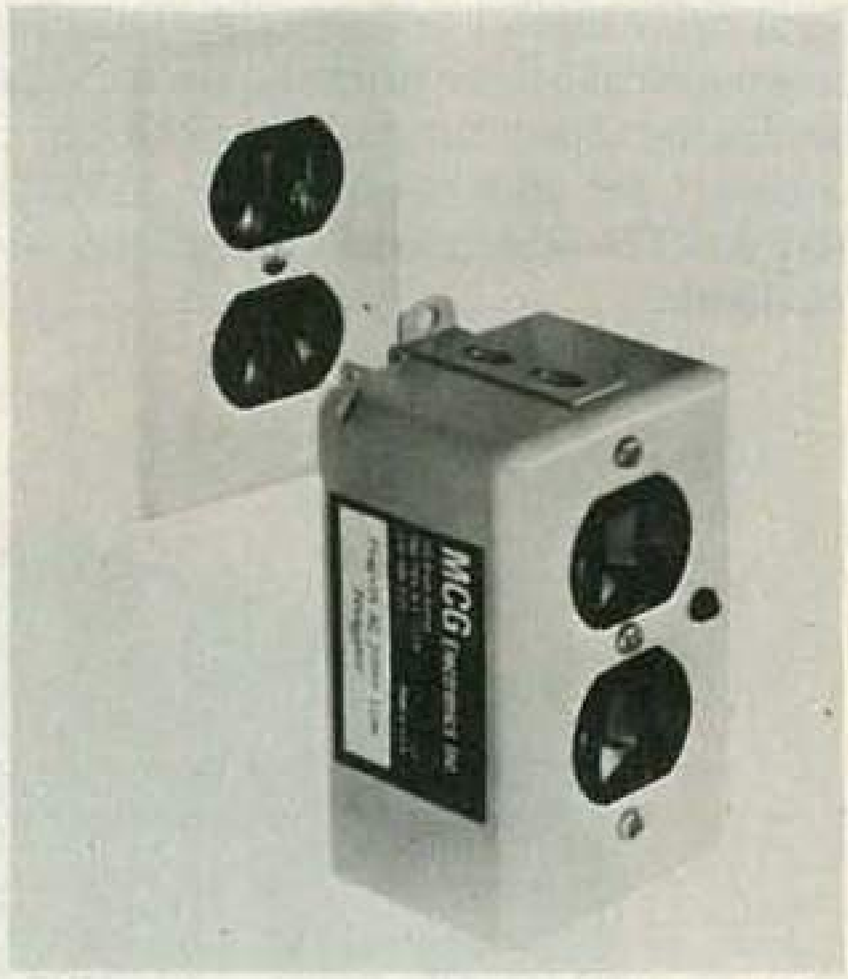
This board also requires a good five-volt power supply. Connect it directly to the board—the fingers at the edge are intended for mounting purposes (there aren't enough of them on a single-sided board for all the inputs and outputs).

The connections are called out in Fig. 82. Use ribbon cable to connect the decoder and latch boards and to connect the latch board to jacks J1 and J2 on the relay-driver board.

With these three boards installed, the conversion to radio control is complete. In the next installment we'll discuss what would be involved in interfacing the robot to a computer. **R-E**

NEW PRODUCTS
continued from page 86

computers, terminals, modems, and printers, as well as office, laboratory, and communications equipment. It incorporates a wall-socket type fixture, so that all equipment can be plugged in easily and any 117-volt AC wall outlet is thus converted into a "dedicated" line.

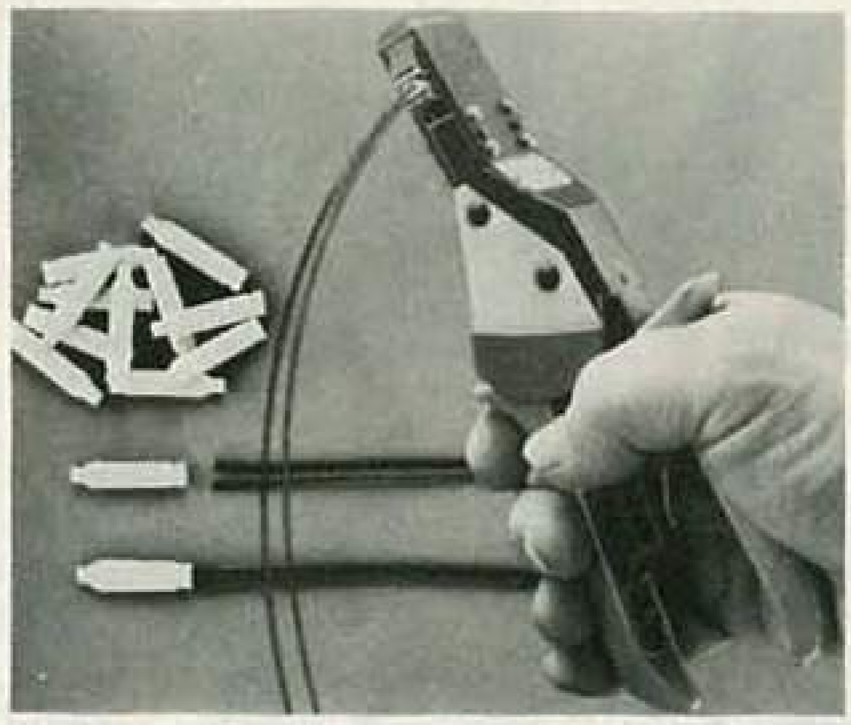


CIRCLE 154 ON FREE INFORMATION CARD

The *model 300* clamps high-energy transients and filters RFI (*R*adio *F*requency *I*nterference) from the AC line. Should a severe transient take place, the device will "fail safe," protecting the equipment without interruption of service or loss of data. The status of the protection is continuously monitored by a LED.

Both low and high-impedance loads are protected from common- and transverse-mode transients. The *model 300* holds down voltage spikes to safe levels, absorbing up to 80 joules of transient energy. It is easily portable, weighing only one pound. Price $135.00—**MCG**, 160 Brook Avenue, Deer Park, NY 11719.

"D" CONNECTOR TOOL, *model CP-200*, is designed to crimp "B"-type insulated wire connectors onto the ends of unstripped wires. Metal "teeth" within the connector penetrate the wire insulation and engage the conductor when the connector is crimped. A built-in ratchet assures that a complete pressing cycle is made before the handles are released. A factory-set mechanical stop prevents over-pressing, thus assuring a high-quality conductive joint.



CIRCLE 155 ON FREE INFORMATION CARD

"B" connectors are available both plain and "jelly"-filled. The latter features "silicone-type grease packing" which wards off contamination of the connection and inhibits oxidation. Both types of connectors are available in packages of 250, 500, and 1000 pieces. Prices: *CP-200*—$55.00; 250 "B" Connectors—$12.00 for the plain, $17.33 for the jelly-filled.—**OK Machine and Tool Corporation,** 3455 Conner Street, Bronx, NY 10475. **R-E**

JAMES A. GUPTON JR.

Computer Control for the UNICORN-1 ROBOT

Part 10—If your robot is going to use computer control, here are some thoughts on the subject that will help you in setting up your system.

WITH THE UNICORN-1 ROBOT OPERATING under radio control, what now? Why, *computer* control, of course! This part will deal with that subject, although, because of its complexity, only in general terms.

For those of you already involved with computers—micro or otherwise—much of what will be discussed here may seem elementary. For those who have not yet been exposed to that fascinating area of electronics we will try to keep things as simple as possible.

What will be covered here will be the *concepts* involved in having the actions of a robot determined by an electronic device rather than by a human operator. That's where much of the challenge of computer control comes in.

A human can exercise his judgment—without necessarily having to think about it—and change the robot's actions to meet the circumstances. The computer also has to exercise judgment, but before it can do that it must be taught—or programmed—*how* to make judgments; that involves a great deal of highly detailed programming.

For those of you who are unfamiliar with computers, it is not enough just to connect a computer to the robot and say, "Go ahead . . . do your stuff." Every action must be pre-planned, and, more important, every consequence of every action must be considered and the appropriate reaction prepared.

That is one reason why we will not present specific programs for robot control but will, instead, talk about the way those programs will have to function.

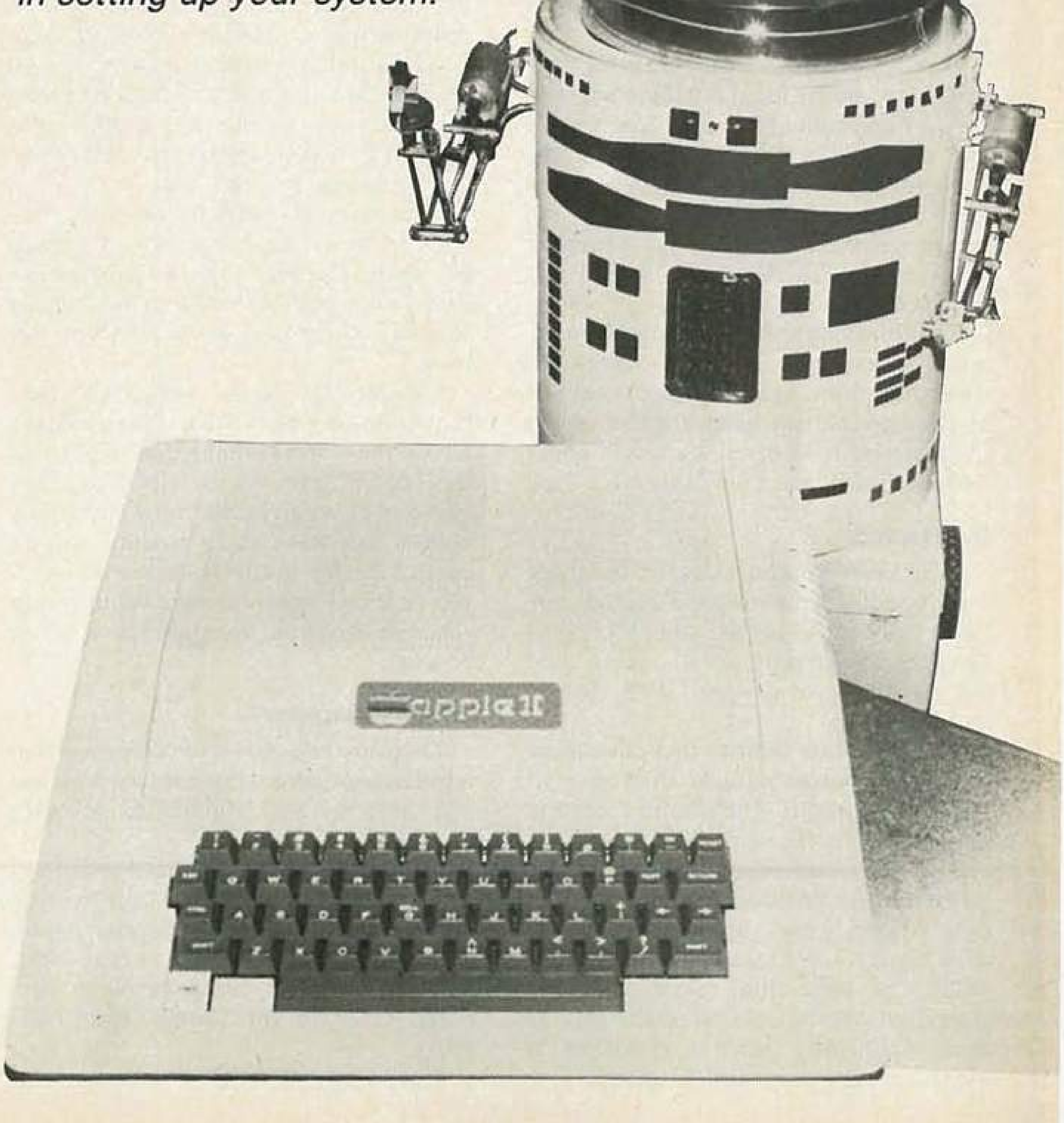
Methods of computer-control

To put it broadly, there are three ways that a computer can be used to control the robot's actions.

The first, and simplest, would substitute a computer, *located outside the robot*, for the command consoles described earlier in this series. That computer would be linked to the robot either by cable or by radio.

The program for that system would be fairly simple and would allow the operator to type in a command, to which the robot would respond. For example, entering "GO" or "G" would cause the robot to move forward; "TURN LEFT" or "L" would cause it to turn to the left, and so on.

That elementary program could be modified to operate with a speech-recognition device—several of which are available for a couple of hundred dollars—to allow the robot to respond to the spoken



word. The vocabulary would be limited (but adequate) but the commands would have to be given to the external computer, not to the robot directly.

The second system would be a program, or series of programs, that would command the robot to perform a predefined sequence of actions.

For example, the robot might be instructed to move forward for ten seconds, stop, raise its right arm in a salute, beep its horn, and then turn around and return to its starting position.

Such programs could become very elaborate, but have a major drawback. Unless the robot is equipped to respond to its environment (and, so far, it isn't) any unknown factor that enters the picture could have serious consequences.

Using the program above as an example, suppose that, unknown to you, the robot is facing a brick wall, five feet in front of it. Shortly after the robot begins to carry out the instructions given to it by the computer, it will run smack into that wall! Not only will that interfere with the rest of the program, but it can also cause damage to the robot and, possibly, the wall. Or maybe, instead of a brick wall, there's a person or a piece of furniture in the way. The overall damage—and its consequences—could be considerably more serious.

In any case where the robot is operating without human intervention, provision must be made for the program to be overridden!

Any program of that nature must contain some means for the human supervisor to stop or alter the robot's actions at any time. That is one reason that the "drop-dead" circuit was included on the latch board (Part 9)—one command would activate that circuit and cause the robot to stop in its tracks, should any unforseen circumstance arise.

The third method of computer control, and the most fascinating, involves the robot having its own, on-board, computer. The precautions given for the second method also hold here. We'll talk about that method in more detail shortly.

Interfacing

Whichever method is chosen, the robot must be equipped to respond to (and, perhaps, "talk back" to) the computer. Fortunately, the circuits already being used by the robot are designed with that in mind.

There are two formats that computers can use to output data or to receive it: *parallel* and *serial*. The parallel format is always used by the computer internally.

The unit of information that the computer uses for communication is called a *byte*. A byte is made up of eight bits (*bi*nary dig*its*)—each one either at a logic-"high" or logic-"low" state—and the computer operates on all eight bits at once. Frequently, when a computer is used to operate a printer, the parallel format is used and eight lines are used to connect to the printer—one for each bit of the byte.

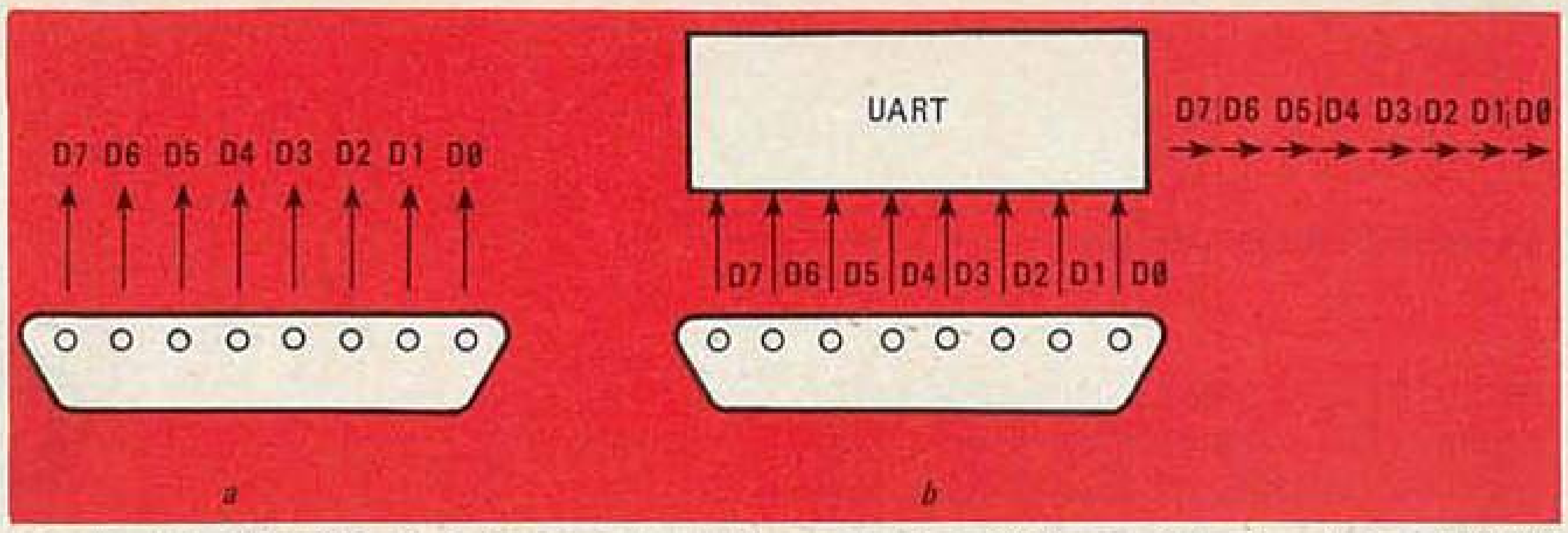


FIG. 83—ALL THE BITS of a byte are sent simultaneously in parallel communications (*a*). A UART (*b*) converts parallel data into serial data for transmission over a single line.

On the other hand, sometimes it is convenient—or even necessary—to transmit computer data using only a single line (by telephone, for example). In that case, the serial format is used. The computer takes each byte and sends it out bit-by-bit, one after the other, indicating the beginning and end of each byte. At the other end, the eight bits are received in the order in which they were sent; when they have all arrived, they are used in parallel. Both of those systems are illustrated in Fig. 83. The device that performs the parallel-to-serial and the serial-to-parallel conversions is known as a UART (*U*niversal *A*synchronous *R*eceiver/*T*ransmitter). UART's would be used if commands were transmitted to the robot by radio.

If you connect your computer to the robot by means of a cable from the computer's parallel port, it would be a good idea to use twice as many lines as necessary (16) and ground every other one. That will help keep electrical noise from getting mixed in with the data.

(For more information on how computers operate see "Your Own Computer" in the October 1980 issue of **Radio-Electronics** and the article on assembly language computers on page 45 of this issue.)

The decoder-, latch-, and relay-driver-boards in the Unicorn-1 use parallel data. Using the same technique as used with the 7402 IC's on the decoder board, any two bits of an eight-bit word (byte) can be NOR'd or NAND'ed to produce a single control bit for the relay-driver board. If you're knowledgeable, more complex and versatile encoding/decoding schemes can be used.

Which computer?

There are two classes of computers that must be considered: those for external use and those that can be mounted on-board the robot.

Almost any computer that has at least one parallel port can be used for the first purpose and it is not our intention to single out one manufacturer's over the other. If you are contemplating buying a computer, refer to the articles mentioned above.

The important thing is that the computer be equipped with a parallel port and that it be flexible enough to meet your needs—present and anticipated. For example, if you are considering using voice control, make certain that there is a speech-recognition board available for your computer.

It should be noted that some computers—such as the Radio Shack *TRS-80* and the Commodore *PET*—do not have parallel ports as such, but that their expansion connectors—frequently used to connect to printers—are actually just that. The thing to look for is eight *data lines*, usually designated "DØ" through "D7." If you have those, you have your parallel port.

You will also want a cassette and/or disk interface to allow you to save programs that you have written for the robot.

One thing you should avoid are inexpensive computers that are actually glorified video games. They generally will not have the facilities you need and it will prove difficult (or impossible) to add them.

The other possibility is a single-board computer that can be mounted in the robot. In addition to a parallel port and cassette interface, that computer must also have a hexadecimal ("hex") keypad for programming, and some kind of LED display, if it is not going to be used together with an external computer. An example of how such a computer would be interfaced to the robot is shown in Fig. 84.

A good computer for the purpose is the *KIM-1*. Unfortunately, that computer was recently discontinued; but you may still be able to find one here and there. Other possibilities include the *SYM-1* (a sort of super *KIM*), the *ELF-II* or the *Explorer/85* (keypad version). Again, refer to the article on page 45. Both the ELF-*II* and the Explorer/85 are manufactured by Netronics, 333 Litchfield Road, New Milford, CT 06776. The SYM-1 is produced by Synertek Systems Corporation, P.O. Box 552, Santa Clara, CA 95052.

Bear in mind that some of those computers may require a power supply other than 5- or 12-volts DC. In that case a power inverter (see Fig. 85) can be used to turn the robot's 12-volt supply into 117 VAC, which the *computer's* power sup-

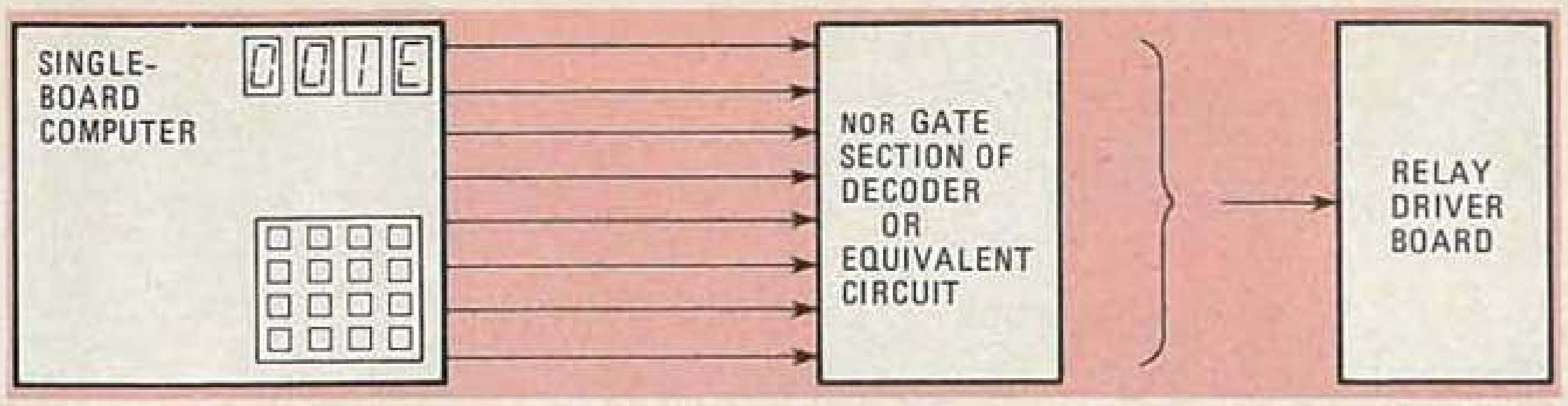


FIG. 84—SINGLE-BOARD COMPUTER can be connected to NOR gate section of latch board or to an equivalent circuit designed to give a single output from a two-bit input. That is only one of many possible schemes.

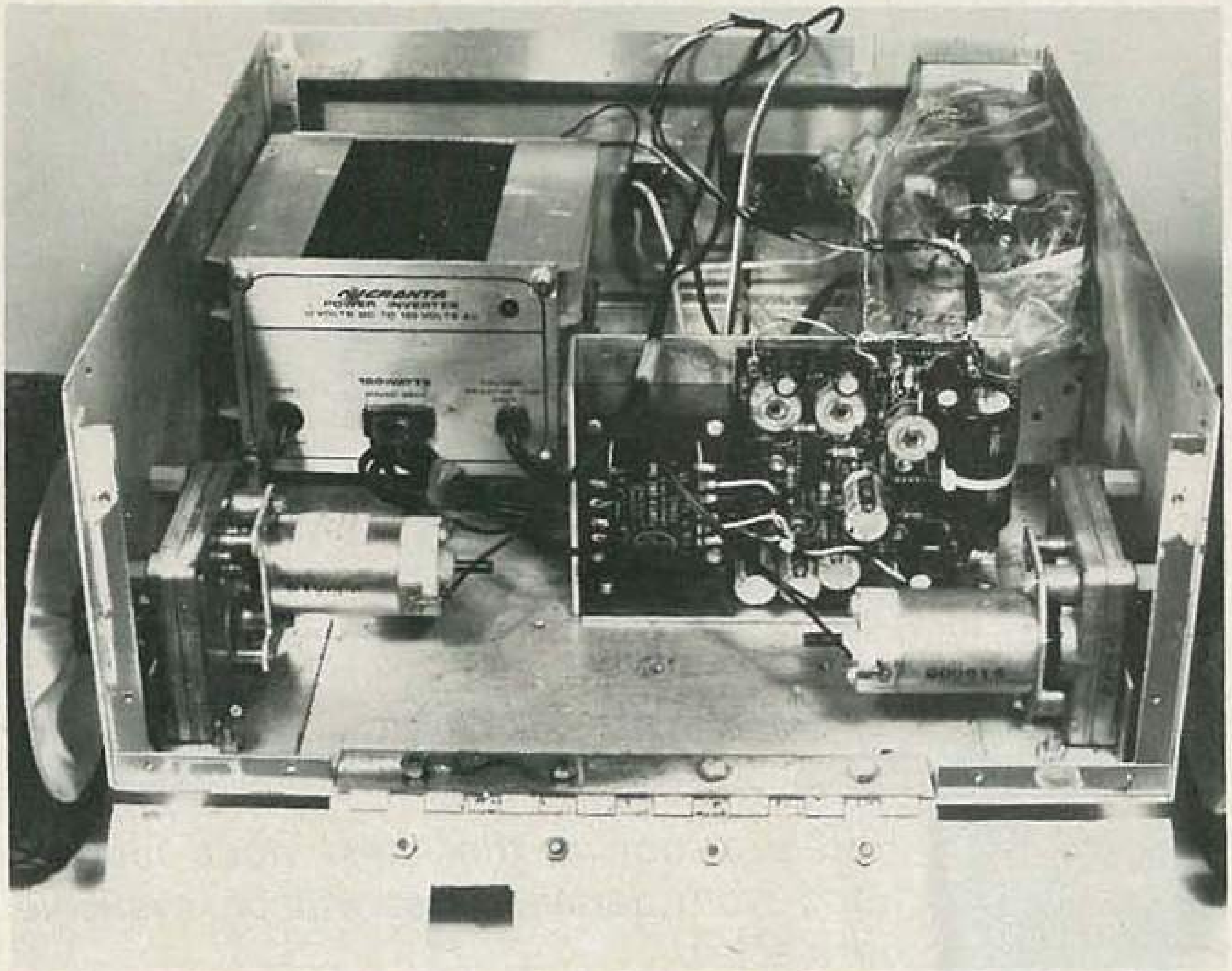


FIG. 85—AN INVERTER (left rear) may be needed if the on-board computer has power requirements other than +5 or +12 volts DC.

ply can then convert readily to its own requirements.

Finally, if you already own a computer but intend to install another in the robot, it would be a good idea to make sure that both computers use the same-type, or compatible, microprocessors. The *KIM-1* and *SYM-1* use the 6502, which is also found in the *Apple II*, OSI *Challenger(s)* and the *PET*, and the Z-80 in the *TRS-80* is compatible with the *Explorer/85's* 8085.

The 1802, used in the *ELF II* and in RCA's *VIP*, is not normally found in larger computers, but that does not mean that an 1802-based single-board computer should not be used in the robot.

The fact that both of your computers use the same microprocessor means that both of them speak the same language, at the microporcessor level. That, in turn, means that you can use your larger computer to develop and debug (troubleshoot) programs to run on the robot's computer and to *download* (transfer from the larger to the smaller computer) those programs, either directly or, if the cassette interfaces are of the same type, from tape.

The programming itself will also be easier, since—assuming that your programs are in machine language and not in BASIC—you will be able to use an assembler, making your work go more quickly and also making it easier to follow the flow of the program.

Programming

As you may have gathered by now, it would be impossible to present computer programs for robot-control, there being so many variables involved.

If you are working with an external computer, you will probably want to work in BASIC or another high-level language, using the OUT command, or its equivalent, to transfer data to the robot.

As mentioned above, the on-board computer will almost certainly have to be programmed in machine language. It's more difficult to work with than BASIC, but it *does* have advantages. Programs take up much less memory space, and also run more efficiently. You may even want to write your "big-computer" programs entirely in machine language through the use of an assembler.

This section has of necessity, been sketchy: after all, even books on the subject have not been able to cover the matter completely.

If you are going to use a computer with your robot, we recommend that you do as much supplementary reading as you can. Personal-computer magazines such as Byte magazine and Interface Age have had special issues dealing with robots, and the subject comes up frequently there and in other computer publications. Another good source of information that is often overlooked is your local library.

Todd Loofbourrow's book, *How to Build a Computer-Controlled Robot* (Hayden Publishing Company) contains a number of robot-control programs written for the *KIM-1* (or *SYM-1*) as well as a number of more generalized flowcharts. Much of the information presented there may be adaptable to your robot.

A very good—although rather technical—article on "An Interactive Programming Language for Control of Robots" by Li Chen Wang appeared in the September 1977 issue of Dr. Dobb's Journal of Computer Calisthenics & Orthodontia. It involves a robotic simulation on a computer's video display and its principles could be adapted to control a "flesh-and-blood" robot. (That issue, #18, Volume II, No. 8, is available in limited quantities from: Dr. Dobb's Journal, 1263 El Camino Real, Box E, Menlo Park, CA 94025 for $2.50, postpaid, second class.) It's worth looking into for readers already familiar with computer programming.

In the next part of the Unicorn-1 series we will take a look at sensors. We will discuss sensors in general, and show you some specific examples that can allow your robot—and the computer that controls it—to respond to the world around it.

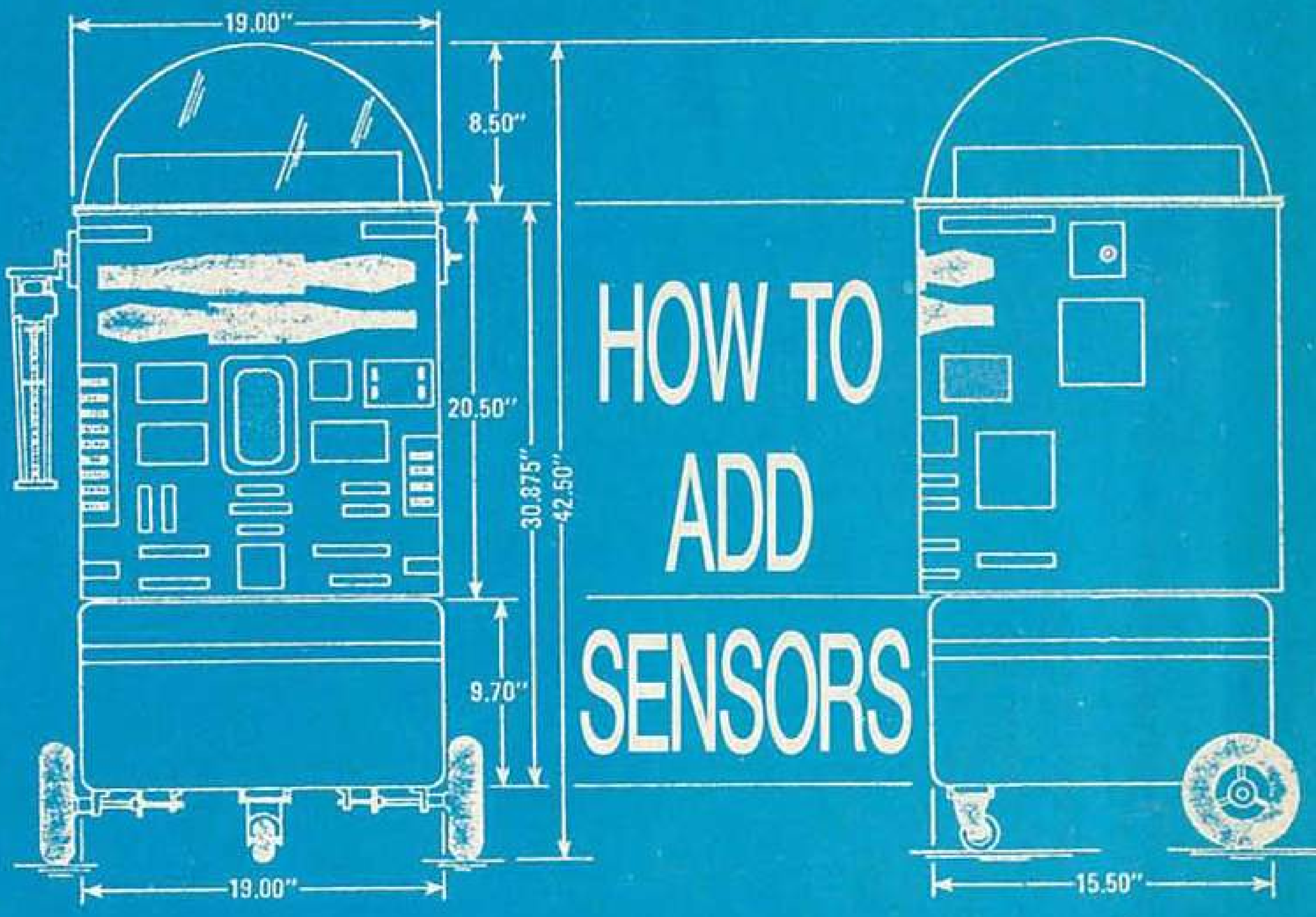
We would like to hear about how you're doing with your version of Unicorn-1. Write (and send photographs) to: ROBOT UPDATE, **Radio-Electronics,** 200 Park Avenue South, New York, NY 10003. **R-E**

"Charlie's OK at fixing computers. He seldom does any damage that an electronic technician can't repair."

Part 11—The better your robot can respond to the world around it, the more useful it will be. Here are two sensors that will enable the robot to "see" and "feel" objects that are in its vicinity.

UNICORN-1 ROBOT

JAMES A. GUPTON, JR.



UP UNTIL THIS POINT, ANY REACTION THAT the robot has shown to events happening around it have actually been those of its operator. Radio- or computer-control has been possible only to the extent that the operator could observe the robot's environment and make the robot react to it. And, even operating in that way, there has been the danger that the robot could "stumble" into something that could not be seen by the operator.

In this installment of the Unicorn-1 series we'll describe two types of sensors that will enable the robot to detect objects in its immediate vicinity and to react to them.

The first is a contact-type sensor that will give the robot a limited sense of "feel" and allow it to know when it has bumped into something.

There are times, though, when it would be better for the robot to be able to sense when it was *about to bump into* something—running into brick walls is one thing; running into people, another!

The second sensor, then, will be of the proximity-type, giving the robot a rather restricted sort of "vision."

Contact sensor

The robot should be equipped with two contact-sensors—front and rear. They are extremely simple in design, as can be seen from Fig. 86, consisting of lever-actuated switches that are connected to rods projecting from the mobility base. Note that the rear sensor-rod is about twice as long as the one for the front sensor. This compensates for the fact that the large driven wheels of the mobility base may project behind it and, naturally, we want the sensor to come into contact with an obstacle before any part of the robot does.

The sensor rods are made from pieces of wire coat hanger, with the paint or lacquer removed to permit good solder joints. The front rod is about 1½-inches long and the rear rod about twice that length. The compression springs can be "liberated" from dried out ball-point pens. The springs are held in place by 4-40 washers soldered to the rods.

A 4-40 cap nut (the kind with a rounded end) can be soldered to the end of each rod to prevent it from scraping or impaling whatever it may come into contact with. Better protection can be provided by applying a liberal amount of silicone sealant to the cap nut to provide a soft, protective surface.

Even better, a small bumper, with a soft covering made from a piece of foam rubber or inner tube, can be constructed and affixed to the end of the sensor rod.

The bushings that fit into the mobility base and allow the sensor rods to move in and out are nothing more than 10-32 × 3/4 machine screws that have been drilled out with a No. 42 drill bit (use a drill press and vise, if you possibly can) and had their heads filed flat to remove the screwdriver slot. Leave enough head, though, to hold the screw in place. Use 10-32 nuts to secure the bushings to the mobility base.

A helpful hint: Fig. 86 shows a half-inch brass washer soldered to the "inside" end of each sensor rod. (The washers are especially necessary if more than one switch is used for each sensor—see below.) *Those* washers should be the last part to be attached.

The end-nut (or bumper), spring and 4-40 spring-stop-washer should be attached to the rod first, and the unit inserted into the bushing. Then, using a wooden block to compress the assembly, and holding the brass washer with a pair of pliers, solder the washer to the end of the rod. Doing this will prevent your getting your fingers burned.

The brackets for the switches can be made from almost any material at hand—metal, plastic, or wood. They support the switches in the proper position and, if two switches are mounted side-by-side, allow the brass washer to contact both switch-levers at the same time.

The original Unicorn-1 used brackets made from scraps of 1½ × 1½ × .0625-inch aluminum, bent as shown in Fig. 86, and drilled to accept two 4-40 mounting screws. The section that fits flush with the mobility base need be no larger than 1/4-inch if 4-40 hardware is used but should be at least 3/8-inch long for 6-32 hardware.

If the mounting holes in the switches are too small for 4-40 hardware, they can be enlarged with a No. 33 drill bit. Be sure to use a vise and to use either a hand drill or a *very slow* electric drill to prevent damage to the plastic switch case.

The completed front and rear contact-sensor assemblies are shown in Fig. 87. If larger switches are used, mounting brack-

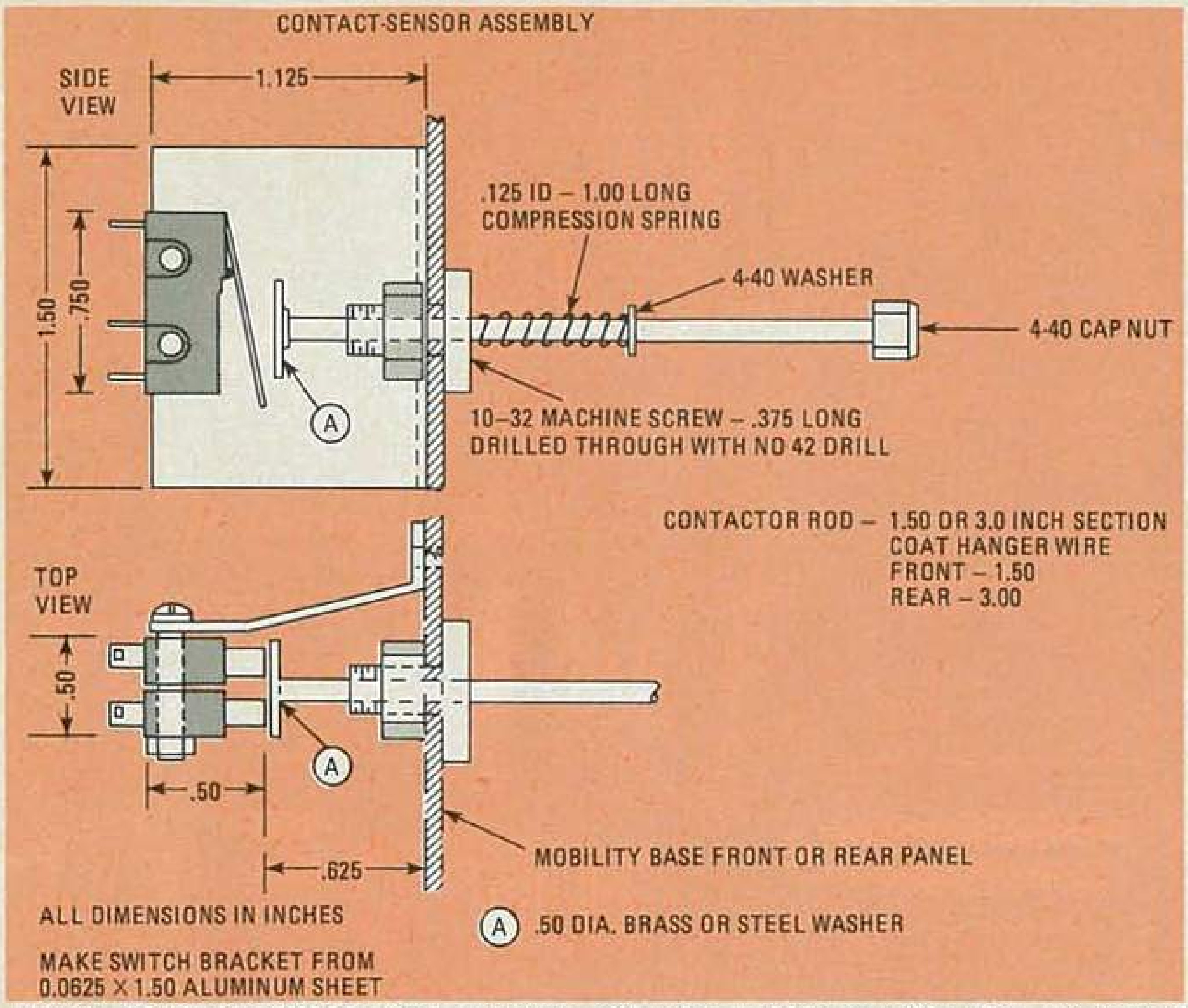


FIG. 86—CONTACT SENSOR tells the robot when it has bumped into something. Cap nut at end of rod should be provided with cushioning material (see text).

ets may not be necesary since the switches can be mounted directly on the bottom plate of the mobility base.

Connection of the switches will be discussed later.

Proximity sensor

While the contact-type sensor described above is extremely useful, there are times when it could prove embarassing (or worse) to have the robot collide with something. It would be better if it

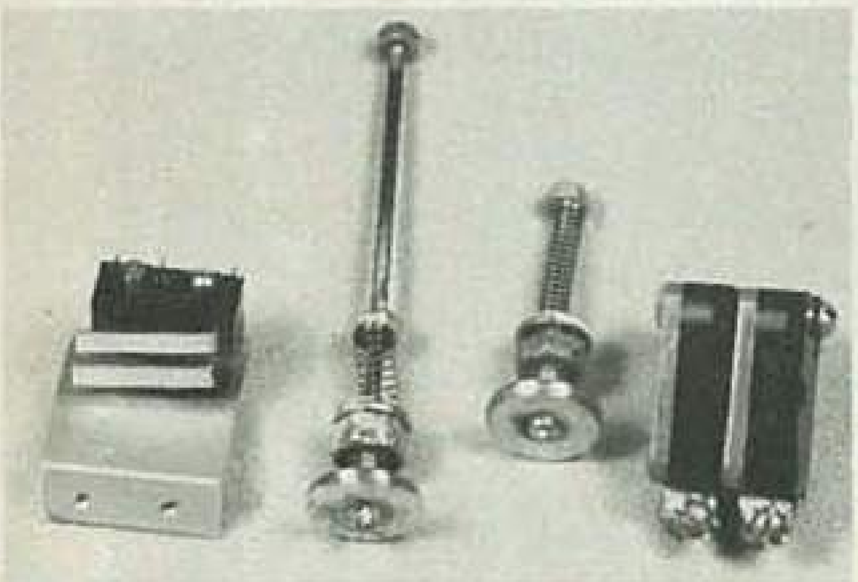


FIG. 87—COMPLETED CONTACT SENSORS used in original Unicorn-1. In this case, dual switch-assemblies were used.

could sense the proximity (nearness) of an object and either stop or, if under computer control, take evasive action.

Figure 88 shows how an infrared-light-type proximity sensor would work. The transmitter, mounted on the robot's right side and angled slightly inward, projects a beam of infrared light that will be reflected by a nearby object to the infrared detector, mounted on the robot's left side and also angled toward the target.

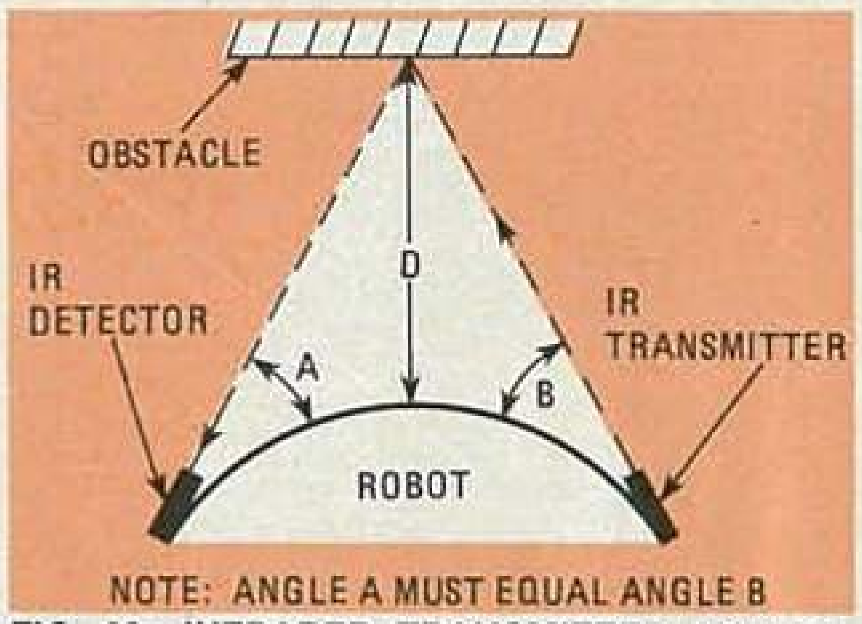


FIG. 88—INFRARED TRANSMITTER AND DETECTOR are mounted on sides of robot's body or dome. Angle A must be equal to angle B.

The distance between the transmitter and the detector, and the angle they form, will determine the distance, D, from the robot that the object can be sensed. The transmitter and detector must be aimed inward at equal angles for accuracy. (Remember that "the angle of reflection equals the angle of incidence;" and, the larger the angle, the farther away—up to about 20 inches in this case—an object can be detected.)

Using infrared light means that the system can be used under almost any lighting conditions since the infrared detector is not very sensitive to visible light. For that matter, the robot could even detect obstacles in the dark—it carries its own "flashlight."

Figure 89 shows the infrared-projector assembly used on Unicorn-1. When used with a lens, the 2174D infrared lamp generates a beam that is usable to a distance of about 20 inches.

The dimensions shown for the lens tube are only approximate, since there are so many variables (lens type, detection distance required, etc.) involved. The best way to find the dimensions you will need is to set up the lamp in its housing at one end of a ruler and to move the lens back and forth until you can see the beam focused into a spot on a screen or sheet of paper placed at distance D—your target distance. Don't forget that D is measured from the front of the robot, and not from the transmitter (or receiver).

Note the distance between the lens and the aperture of the transmitter assembly and make the lens tube that length. Critical adjustments can be made later by adjusting the position of the lamp housing slightly. The final assembly step, before mounting the projector on the robot, is to glue the lens in place in the tube using either epoxy or lens cement. Take care

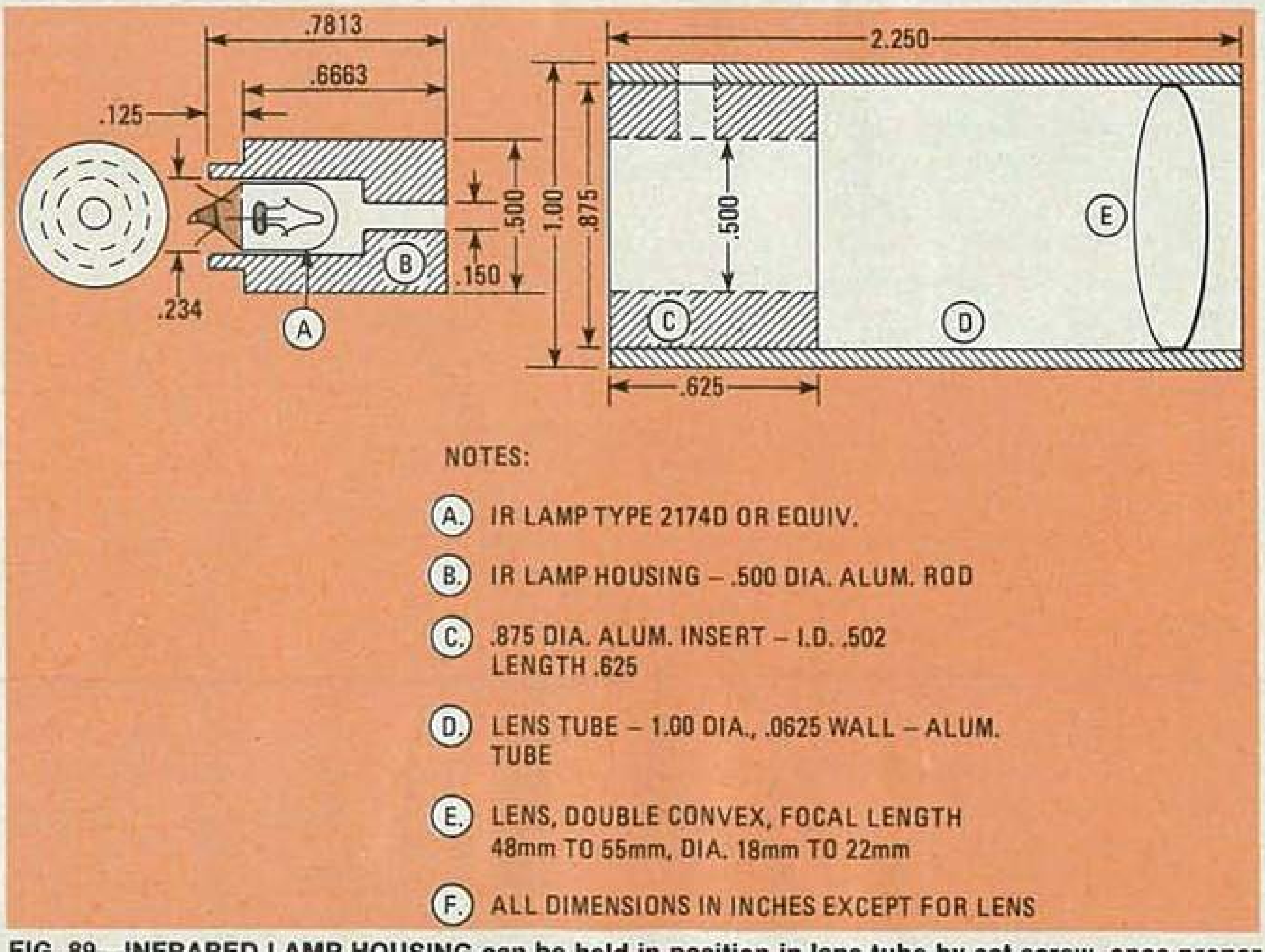


FIG. 89—INFRARED LAMP HOUSING can be held in position in lens tube by set screw, once proper position has been determined.

PARTS LIST—CONTACT SENSORS		
Item	**Description or quantity**	**Source**
Contact rod	1.5 inches	coat-hanger wire
"	3.0 inches	"
Mobility-base bushing	10−32 × 3/8 flat-head screw, (2)	hardware store
"	10-32 nut (2)	"
Cap nut	4-40 (2)	"
Compression spring	.125 I.D., 1 inch long (2)	ball point pen
Washer	4-40 steel (2)	hardware store
"	.5-inch brass (2)	"
Lever-type switch	2 or 4	**Radio Shack** (catalog No. 275-016) or equivalent
Switch bracket	1.5 × 1.5 × .0625 aluminum (2)	scrap or hardware store

PARTS LIST—PROXIMITY SENSOR		
Item	**Description or quantity**	**Source**
TRANSMITTER:		
Infrared lamp	2174D, 12-volts	electronic-supply house
Lamp housing	.5-inch aluminum rod	hardware store
Lens tube	aluminum tubing, 1-inch O.D. × 2.25 inches long	"
Lens & lens cement	double-convex, 48-55mm focal length, diam. to fit lens tube	**Edmund Scientific** 101 E. Gloucester Pike Barrington, NJ 08007

Item	**Description or quantity**	**Source**
RECEIVER:		
Sensor housing	5-inch aluminum rod & washer	hardware store
Lens tube	aluminum tubing, 1-inch O.D. × 2 inches long	"
Lens & lens cement	double-convex, 20-30mm focal length, diam. to fit lens tube	**Edmund Scientific**
PC board	1 ($2.50 + $1.50 S&H if total order less than $15.00)	**Hal-Tronix** P.O. Box 1101 Southgate, MI 48195
R1	68 ohms, ½-watt	
R2	22,000 ohms, ¼-watt	
R3	10,000 ohms, ¼-watt	
R4	4700 ohms, ¼-watt	
IC1	7404 hex inverter	
Q1	2N2222 or equivalent	
Q2	FPT-100 or equivalent (Radio Shack 276-130)	
D1	1N5227 3.6-volt Zener diode	
D2	1N5231 5.1-volt Zener diode	
D3	1N4001, 50PIV, 1-amp diode	
RY1	5-volt DPDT DIP relay (Radio Shack 275-215 or equivalent)	

not to get any of the adhesive on the lens. The completed transmitter assembly is shown in Fig. 90.

A diagram of the infrared-receiver assembly is shown in Fig. 91. As in the case with the transmitter, the dimensions are approximate. To determine the final dimensions, a method similar to the one outlined above is used.

First, cover the aperture of the detector housing with a translucent material, such as *Scotch* brand *Magic Tape*, to make a focusing screen. Attach the detector housing to a ruler and aim the ruler at a white or light gray surface placed at distance D. When making your final calculations, don't forget about the angles involved! Move the lens back and forth along the ruler until a sharply defined spot is seen on the focusing screen. The distance between the lens and the end of the detector housing will determine the length of the lens tube.

As in the case of the projector, cement the lens to the focusing tube and perform the critical focusing adjustment with the detector housing.

In performing these measurements, the projector and receiver assemblies should be placed in the positions they will occupy when mounted on the robot, and be angled accordingly. If this is not done, the results of the measurements will be invalid.

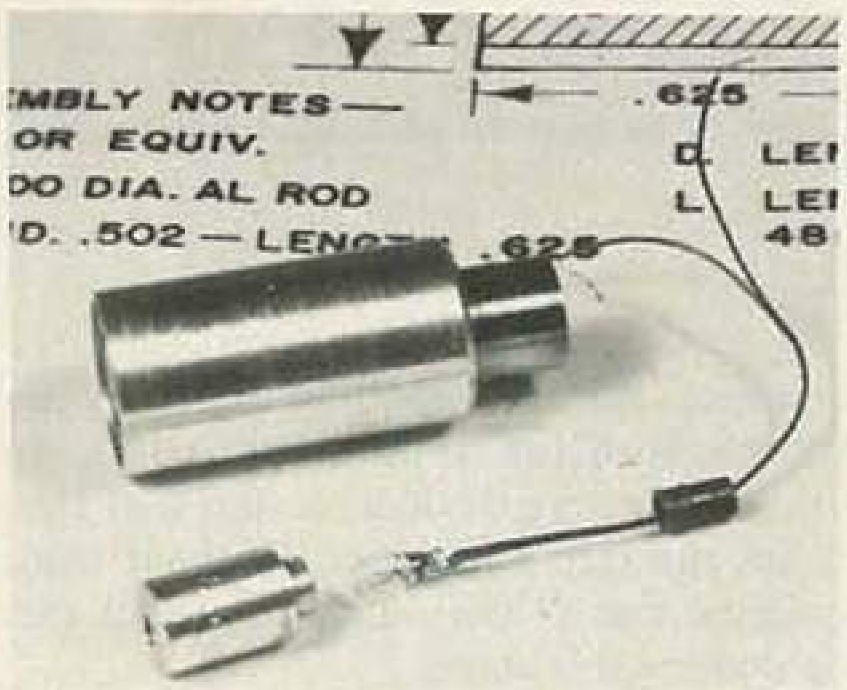


FIG. 90—UNICORN-1's infrared transmitter. Note insulating sleeve for lamp.

Receiver circuit

Both the transmitter and receiver can be operated from the robot's 12-volt power supply. A schematic for the receiver is shown in Fig. 92 (and the foil pattern and parts-placement diagram in Figs. 93 and 94, respectively).

The heart of the receiver is an FPT-100 infrared phototransistor (Radio Shack part No. 276-130 is an acceptable substitute). Its collector is connected to the 12-volt supply through a 10K load resistor, R3. The collector is also connected to pin 1 of IC1 through a 22K series resistor and through a 1N5227 3.6-volt Zener dioide (D1). That keeps pin 1 at a logic "high" when the detector is receiving no input.

The IC supply voltage of 5.1 volts is provided by D2, a 1N5231 Zener diode. This diode also provides the coil-voltage for RY1, a DIP relay of the same type used on the relay board described in Part 7 of this series. The circuit operates as follows:

When the infrared sensor, Q2, is at the optimum distance from a reflective obstacle, the reflected infrared light is at a maximum. The sensor is biased into a state of saturation and its collector voltage drops to zero. The 3.6-volts present at pin 1 of IC1 also drops to zero, causing the output at pin 2 to go from 3.6- to five volts (logic "high"). This biases transis-

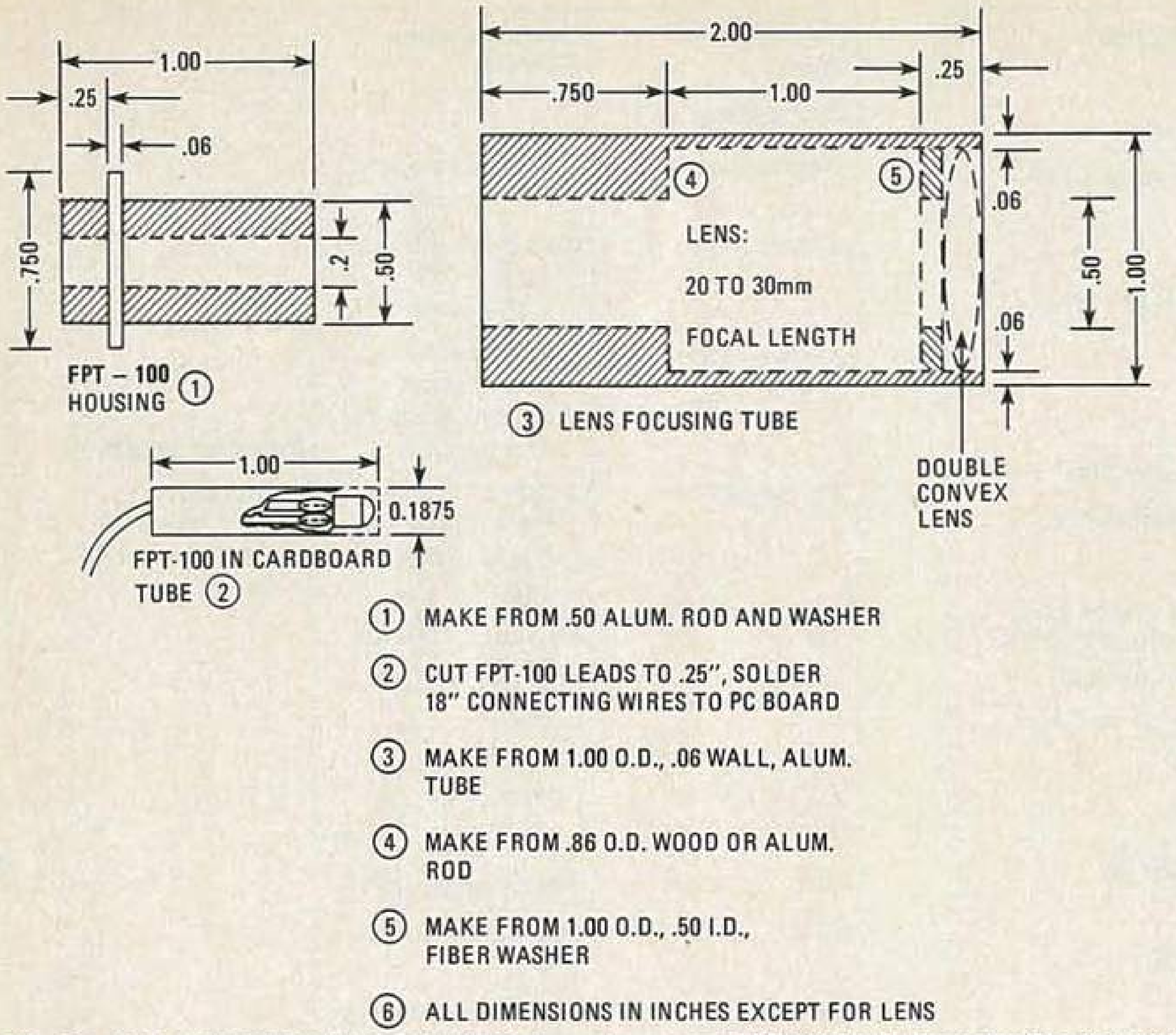


FIG. 91—USE A CARDBOARD OR PLASTIC sleeve to prevent FPT-100 leads from shorting to metal housing.

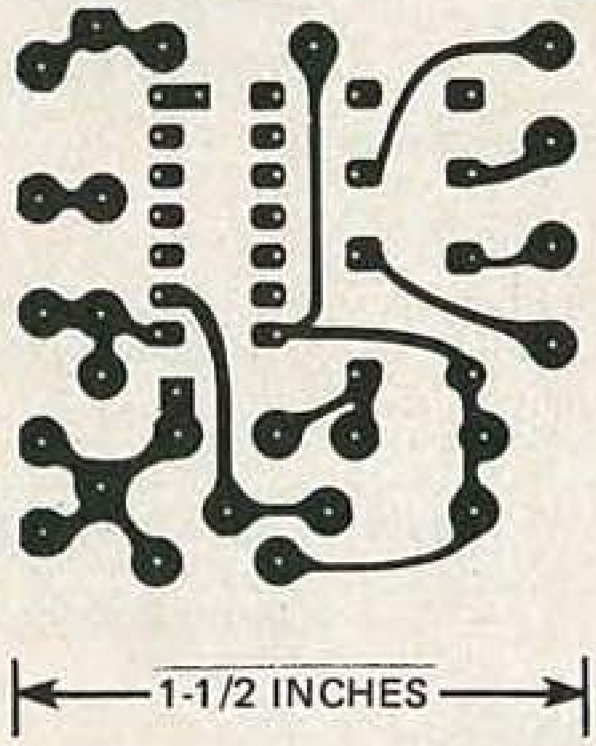


FIG. 93—YOU CAN ETCH detector board yourself from this pattern. Ready-made boards are also available (see parts list).

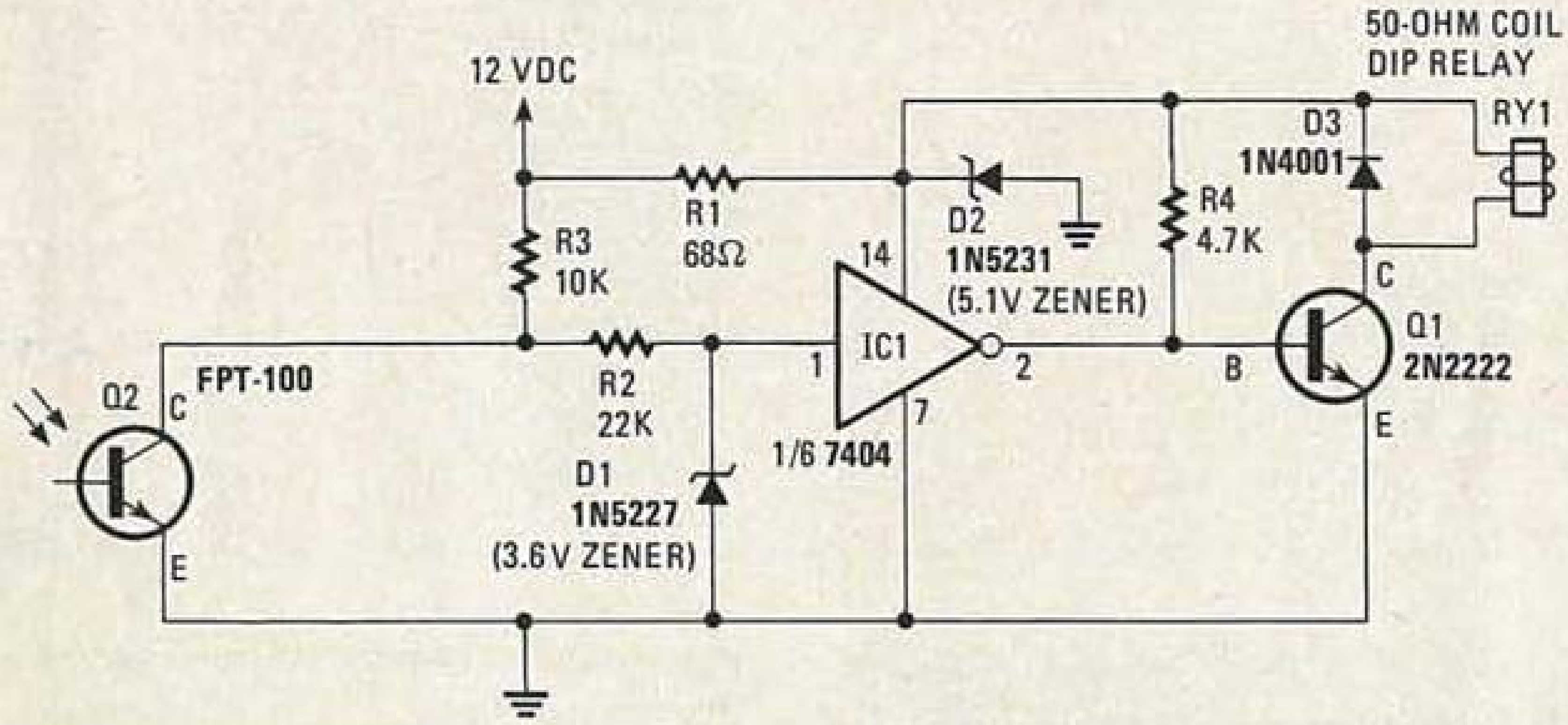


FIG. 92—INFRARED-DETECTOR circuit is simple enough to be built on perforated construction board.

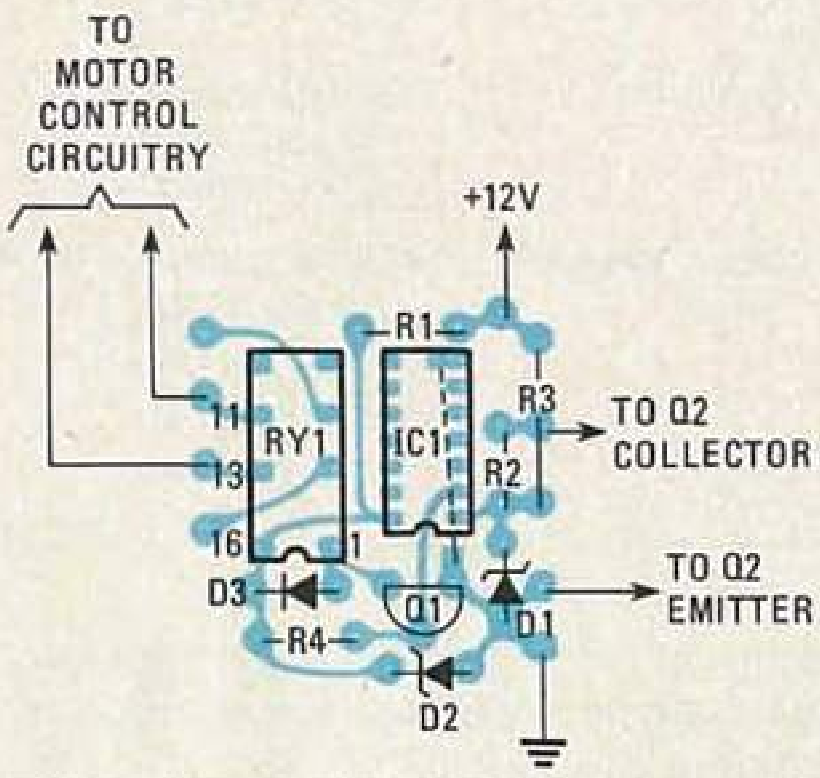


FIG. 94—DETECTOR BOARD is connected to FPT-100 sensor by 18-inch leads. See text for motor-control connections.

We've been receiving a lot of correspondence from readers who are building—or contemplating building—their own versions of Unicorn-1. We'd like to see more, along with nice sharp photographs, so we can publish a segment showing off those robots and presenting some of the innovations that you've come up with. Write to **Radio-Electronics,** 200 Park Avenue South, New York, NY 10003 and mark your envelope "ROBOT UPDATE."

tor Q1, a 2N2222, into saturation, causing current to flow through the coil of the relay and opening the relay's normally-closed contacts, thereby cutting off power to the appropriate control circuitry.

Connection to robot

Depending on how advanced your own robot is, the signals provided by the sensor circuitry can be used in several ways.

If the robot is still operating at the end of a "tether," the contact-sensor switches and the proximity-sensor relay can simply be connected in series with the motor circuits (like the limit switches) and used to cut power to the motors when an obstacle is detected. This is why you might wish to use two switches each for the front and rear contact-sensors—one switch can control the right-hand wheel, and one the left-hand one. Unused switch or relay contacts can be used to actuate the robot's horn (or some other audible or visible signaling device) to alert you that it has run into difficulties. Without logic circuits, there's not much more that can be done at this stage.

If the robot is using radio- or computer-control, the output of the detectors can be connected to the appropriate "drop-dead" sections of the latch board (see Part 9) to achieve the same results.

Finally, if you are using a computer, a program can be written to make use of the "drop-dead" signal. For example, the computer could be programmed to respond to that signal and make the robot back up a bit, make a 45-degree turn, and check again for an obstacle. If none were present, it could continue its travel. And that just scratches the surface of the responses that could be programmed.

The rest is up to you, for this is the end of the Unicorn-1 series. We've shown you how to build a working robot, and how to enhance it with radio- and computer-control. As you continue to work with your robot you'll find its capabilities limited only by your imagination and resources.

Those of you who have built your own robots can take pleasure in knowing that you are advancing the science of robotics. In the near future, much of the hazardous and tedious work now performed by humans will be carried out by robots.

Even now we are seeing robots explore parts of the solar system that man will not visit in person for tens—or hundreds—of years. Enormous progress is being made in creating robots to serve in areas where man's help is either unnecessary or impossible to provide. What will be *your* contribution to the age of robotics? **R-E**