



BUILD THIS AUTOMATIC PARTS TRAY

Learn how to use stepper motors, and build a great system that simplifies PC-board assembly in the process.

JAMES J. BARBARELLO

Stepper motors are simultaneously exciting and intimidating for the hobbyist. There's something fascinating about a precision device with so many uses. That fascination dampens, however, when you consider the logistics of obtaining steppers, not to mention the hardware and software required to drive them. Wouldn't it be nice to see a complete project using parts obtainable in small quantities at low cost?

Well, this project does just that. Using a readily available 5 volt stepper motor and a handful of common parts, we'll create a computer-controlled device called the Automated Parts Tray (APT). Using a short and simple QBasic program, APT demonstrates the principles of optimizing PC-board assembly. APT uses a stepper-controlled rotating parts bin along with a graphical display of PC-board component locations to help ensure that the right parts are inserted in the right spots on the board in optimal order of assembly.

APT can handle boards up to 6 x 8 inches. In addition, the project can be expanded easily to include closed-loop control. Further, it can even be used as the basis for a mini PC-board drilling system. (Those enhancements will be presented in future articles.) Best of all, you don't need a lot of money or special mechanical skills. All key parts are readily available from a single, well-established mail-order source, and parts cost about \$30.

All about APT. APT is a simplified adaptation of a semi-automatic electronics manufacturing system that has been in commercial use for years. The system is semi-automatic in that an operator must manually pick up and insert each part, but the actual part and its location are automatically determined and displayed.

In the commercial version, a series of trays are stacked vertically like pies in a dessert display in a diner. Each tray contains several bins. The mechanism is such that all bins but one are covered. The cover can be visualized as a pie from which one slice has been removed. The area of the removed slice corresponds to the exposed bin. Each bin contains a specific part (a 10K resistor, a 2N2222 transistor, and so on).

The PC board being assembled mounts in a holder in front of the operator. To prepare for a part to be inserted, an X-Y table under the PC board moves a solid-state light source (a high-intensity LED or low-intensity laser) directly under a hole in the PC board where one lead of the part to be inserted will go. Then a parts tray rotates so the bin containing the correct part is exposed. The operator takes a part from the tray and inserts it into the position indicated by the lighted holes.

Our version contains one tray with twelve bins. However, the software can accommodate tray changes during parts insertion, thereby affording an unlimited number of bins. And instead of using a mechanically complicated X-Y table and solid-state light

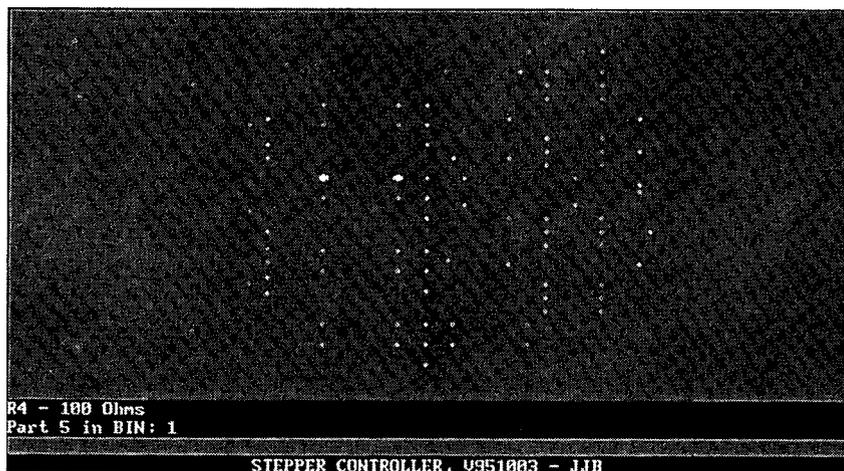


Fig. 1. The automated-parts-tray screen displays a grid overlaid with mounting holes for each component. The current component is highlighted.

source, our version displays a graphical replica of the PC board, all component holes, and a special representation of where the current part should be inserted. Figure 1 shows an example.

The mechanics of this project are quite simple, for two reasons. One is our use of an easily obtainable rotating "Lazy Susan" tray available anywhere kitchen products are sold. (We had good luck with a *Rubbermaid brand* tray.) Second is that we control tray movement using a direct-drive system, thereby eliminating the need for lead screws or gears. So let's get started.

The Stepper and Drive Circuit. The stepper motor is a two-phase, four-wire type. It consists of a permanent-magnet rotor and two field coils, as shown in Fig. 2. Table 1 lists the specifications for the selected motor. When the field coils are switched in the proper sequence, they attract the rotor pull it to a precise position, and hold it there. By energizing coils A and B in the sequence shown in Table 2, the rotor will move precisely 7.5°, which amounts to 48 discrete steps through its rotation.

In Table 2, note that the four inner columns represent two things: The motor winding leads (A, A', B, B'), and the PC parallel-port pin numbers that control those leads. Those numbers correspond to the pin numbers shown in the schematic (Fig. 3). Pin 2 represents the least-significant bit, and Pin 5 represents the most-significant bit. Column six of Table 2 shows the decimal value that should be written to the port to achieve the desired bit pattern for each step in the sequence.

As shown in Fig. 3, it doesn't take much in the way of electronics to drive a stepper. The circuit contains four identical functional blocks. The

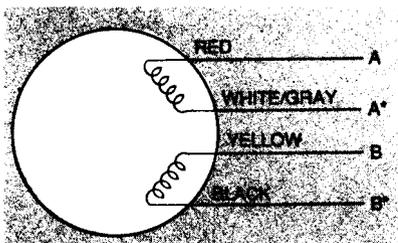


Fig. 2. A two-phase, four-wire stepper motor consists of a permanent-magnet rotor and two field coils.

TABLE 1-STEPPER MOTOR SPECIFICATIONS

Item	Description
Motor Size	Bipolar (2 phase) AIRPAX stepper motor (LB2773-M1)
Weight	2.25 (D) x 0.99 (H) inches
Electrical	0.61 lb
Resolution	5-volts DC, 800 mA, 6.25 ohms
Shaft	7.5 degrees/step
Mounting Holes	0.25 (D) x 0.75 (L) inches
Torque	Two 0.2-inch mounting holes, spaced 2.6 inches apart 100 g-cm (detent), 1080 g-cm (holding)

TABLE 2-MOTION CONTROL SEQUENCE

STEP	A(5)	B*(4)	B(3)	A*(2)	Decimal
1	1	0	1	0	10
2	0	0	1	1	3
3	0	1	0	1	5
4	1	1	0	0	12

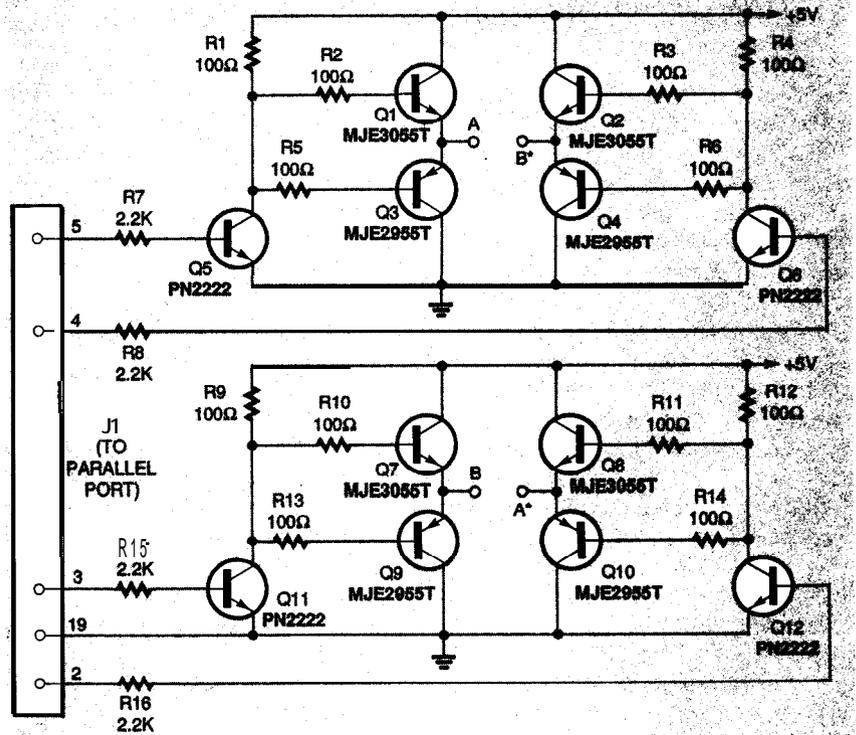


Fig. 3. The driver circuit allows a standard PC parallel port to alter the direction of current flow in both windings of the stepper motor according to the states of the four inputs.

purpose of each block is simply to provide a path from one end of a motor winding to either +5 volts or ground. By alternately switching the polarity of the voltage applied across the windings, we can cause motion to occur.

To see how that works, let's concentrate first on the block that controls the A lead. That block contains Q1, Q3, and Q5, along with the associated resistors. If pin 5 of J1 goes high, Q5 conducts, bringing its collector near ground. That in turn forward-biases

Q3, which brings its emitter near ground. Of course, V_{CE} of both Q5 and Q3 depends on the current being drawn by the load.

Now let's examine the block that controls the A' lead, including Q8, Q10, and Q12, and the associated resistors. If pin 2 of J1 goes low, the collector of Q12 goes high. That in turn causes Q8 to conduct, and Q10 to remain off. So, with A low and A' high, a current path has been established through Q8, coil A' of the stepper motor, and Q12.

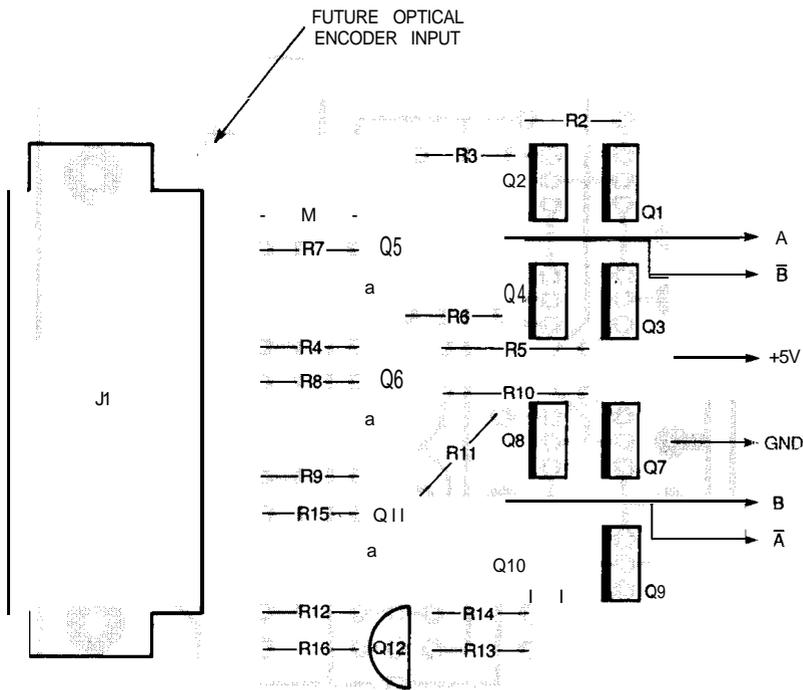
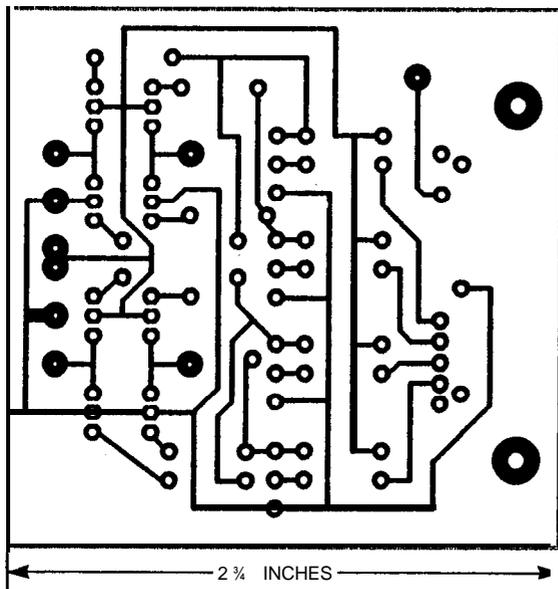


Fig. 4. Mount all components as shown here. A future installment will show how to use the optical encoder inputs.



Use this foil-pattern when etching the PC board.

Moving the Stepper. By driving input pins 2-5 in the proper sequence, we can cause motion to occur. We've already seen the motion-control sequence in Table 2. The question now is how to deliver that sequence in a format acceptable to the motor. The code fragment in Listing 1 shows how. Note that we sequentially output the decimal values from column six of Table 2, with a delay of about 150 ms

after each. The delay is required to accommodate the mechanical inertia of the stepper motor. Without the delay, the control sequences would arrive from the PC so fast that the motor would simply sit there and chatter!

Power Considerations. Many stepper-motor control circuits use a current-limiting resistor to prevent exces-

LISTING 1— MOVING THE STEPPER

```
OUT 888, 10 : GOSUB DELAY
OUT 888, 3 : GOSUB DELAY
OUT 888, 5 : GOSUB DELAY
OUT 888, 12 : GOSUB DELAY
```

```
...
END
```

DELAY:

START! = TIMER

```
WHILE (TIMER-START!) < 0.15 : WEND
RETURN
```

sive current from causing the motor to overheat. In our circuit, the relatively large current demand of the motor causes a measurable voltage drop across the power-providing transistors (in the preceding example, Q3 and Q8). Each will have a V_{BE} drop approaching 1 volt. Therefore, the stepper motor coil sees a net of only about 3 volts. With a coil resistance of 6.25 ohms, the current provided is then $3/6.25$, or about 480 mA. That is well within the motor's dissipation capability so no current-limiting resistor is required.

The tradeoff, of course is that the motor provides less than maximum torque. That's acceptable in our application, but it might not be in others. You could increase torque by increasing the supply to six volts without modifying the circuit. You might be tempted to increase the supply to seven volts to offset the V_{BE} drops in the transistors and provide full power to the coils. That increase is not recommended, however as you will exceed the motor's ability to dissipate heat, leading naturally enough, to overheating.

We calculated current demand of each coil in this circuit configuration as about 400 mA. That implies that a 1-amp power supply should be sufficient. However depending on the actual V_{BE} drops across the transistors, as well as variations in the motor coils, that value could increase to 1 amp or even more. To provide a margin of safety we recommend use of a 1.5- or 2-amp power source.

There are many sources for new 5 volt, 1.5-2 amp power supplies. However, you can save a bundle by buying surplus. For example, some suppliers sell suitable power supplies for less than \$10. A potential draw-

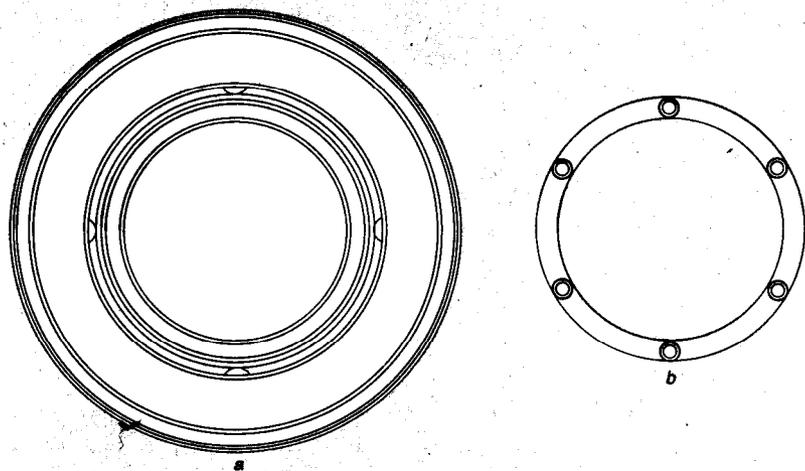


Fig. 5. The rotating tray—the complete assembly is shown in a, and the ball-bearing ring in b.

various diameters; to be consistent with our prototype, try to obtain one that has about a 10-inch diameter. Figure 5-a shows a bottom view of a typical tray. It has a concentric ring that is press-fit under four equally spaced tabs. Under the ring is a ball-bearing assembly, as shown in Fig. 5-b. Holding the tray firmly, distort the concentric ring so it can slip past one of the tabs, then slide the ring free of the tray and discard the ring. Remove the ball-bearing assembly and save it.

Now we have to find the exact center of the tray. That is most easily accomplished with a center finder. If you don't have one, you can use a clear plastic protractor and a straight edge. As shown in Fig. 6, place the two corners of the protractor against the inside lip of the tray and draw a line

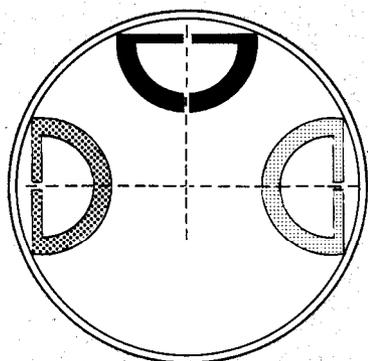


Fig. 6. Finding the center of the tray using a protractor and a straight edge; the point where the lines cross is the center of the circle.

back of that type of supply is that it may require a minimum load at all times. If that minimum isn't met, voltage may rise, for example, to about 5.3 volts. That presents no problem in our application.

Construction. Begin construction with the motor-control circuitry. A PC board layout accompanies this article; the parts-placement diagram appears in Fig. 4. Install the sixteen resistors first. Then install the eight TO-220 package transistors, ensuring both that you install the MJE3055s and MJE2955s in the right positions, and that they have the correct orientation. Next install the four TO-92 transistors (Q5, Q6, Q11, and Q12), again with the proper orientation. Now remove the connectors (if any) on the ends of the

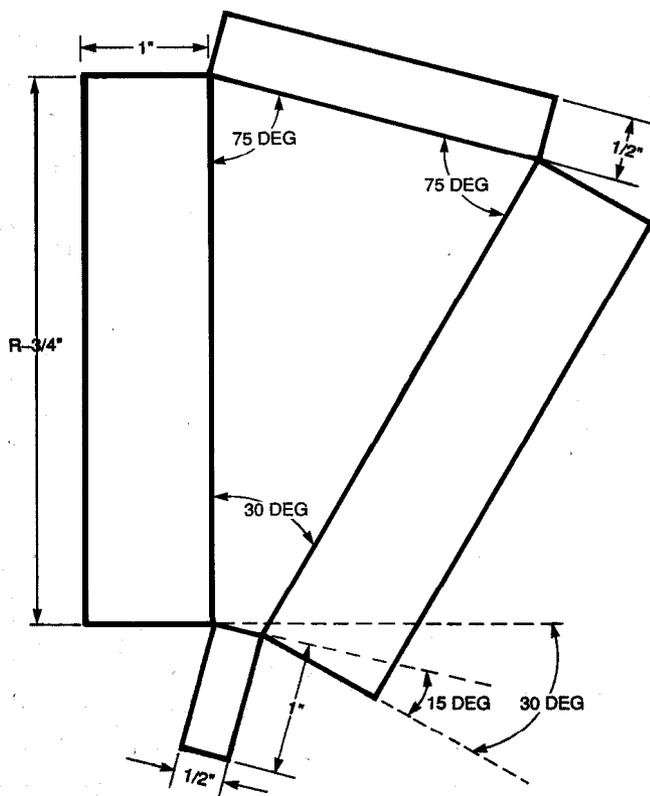


Fig. 7. Use this pattern to create the bins. The length of a side is given by the radius of the tray minus three-quarters of an inch. You'll need twelve of these.

stepper motor leads, and connect them to the appropriate points on the PC board. Attach the positive and negative power supply leads to the PC board.

Now let's look at the mechanics, starting with the tray. Trays come in

from the center marker on the straight portion of the protractor through the 90° indicator on the protractor's arc. Do the same thing at three or more locations on the tray. Where the lines cross is the exact center of the tray (in geometric terms, each protractor

PARTS LIST FOR THE AUTOMATIC PARTS TRAY

R1-R6, R9-R14—100-ohm, 1/4-watt resistor
 R7, R8, R15, R16—2200-ohm, 1/4-watt resistor
 Q1, Q2, Q7, Q8—MJE3055T NPN transistor, TO-220 case
 Q3, Q4, Q9, Q10—MJE2955T PNP transistor, TO-220 case
 Q5, Q6, Q11, Q12—PN2222 NPN transistor, TO-92 case
 J1—DB-25 connector, female, PC-mount
 5-volt DC, 6.25-ohm coil, bipolar stepper motor (Airpax LB82773-M1; JAMECO I17954 or equivalent); PC board; 5-volt/2-amp power supply (JAMECO 107326, 109276, or equivalent); 2.5-mm female power jack; 2.5-mm male power plug; Universal shaft coupler (JAMECO 106606 or equivalent) (2); Rubber coupler (JAMECO 106622 or equivalent); "Lazy Susan" tray (Rubbermaid or equivalent, 10-inch diameter); 1/4-20 × 1 1/2-inch machine bolt; 1/4-20 nut (2); 1 3/4 × 4-inch aluminum or plastic panel; #4 sheet metal screws (4); #6 or #8 sheet-metal screws (2); 24 × 36-inch piece of "Oaktag" or poster paper; 1/2-inch plywood; 1/4-inch Luan mahogany plywood; glue, nails, DB-25 extension cable, solder, wire, etc.

Note: The following are available from James J. Barbarello, 817 Tennent Road, Manalapan, NJ 07726: PC Board; APT-PC (\$12.00). Software including source and executable code for all software in the series, sample data files, and an enhanced version of the APT software (including the optical encoder application); APT-S (\$12.00). All prices include shipping. International orders add \$5.00 (U.S. funds only). NJ residents must add appropriate sales tax. The author will accept phone calls 6-8:00 PM EST., Monday through Friday **ONLY** (908-536-5499). The author will gladly answer written questions if accompanied by a self-addressed stamped envelope.

edge is a chord, and the line you draw is a perpendicular bisector of that cord. Perpendicular chord bisectors are, by definition, along a radius, and therefore cross the circle's center).

Drill a 1/4-inch diameter hole in the

LISTING 2—STEPPER CONTROL PROGRAM

```

REM** STEPPERS.BAS (c) 1995, JJ Barbarello
REM** V951007
CLS : DEF SEG = 64: DEFINT A: add = 888
DIM a(4): a(1) = 5: a(2) = 3: a(3) = 10: a(4) = 12
abinold = 1: ainit = 12: OUT add, ainit
COLOR 15, 1: LOCATE 2, 1: PRINT SPACE$(79)
LOCATE 2, 26: PRINT "APT STEPPER CONTROLLER TESTER"
COLOR 7, 0: LOCATE 10, 20: PRINT "Position Tray At Bin 1, then press Enter"
waitforenter:
a$ = INPUT$(1)
IF a$ <> CHR$(13) THEN SOUND 800, 1: SOUND 500, 1: GOTO waitforenter
LOCATE 10, 20: PRINT SPACE$(40)
loop01:
LOCATE 10, 27: PRINT "TRAY CURRENTLY AT BIN: "; abinold
LOCATE 20, 10: PRINT SPACE$(60)
LOCATE 20, 23: LINE INPUT "Which Bin (1-12, Enter to end)... "; abin$
IF LEN(abin$) = 0 THEN END
abin = VAL(abin$): IF abin < 1 OR abin > 12 THEN BEEP: GOTO loop01
abin2 = abin: IF abin2 < abinold THEN abin2 = abin2 + 12
asteps = abin2 - abinold
SELECT CASE asteps
CASE 1 TO 6
lo = 1: hi = 4: steps = 1
CASE IS > 6
lo = 4: hi = 1: steps = -1: asteps = 12 - asteps
CASE IS < 0
lo = 4: hi = 1: steps = -1: asteps = -asteps
END SELECT
OUT add, ainit
bin = abinold
FOR i = 1 TO asteps
FOR j = lo TO hi STEP steps
OUT add, a(j)
IF i > 1 AND i < asteps THEN delay = .075 ELSE delay = .125
start! = TIMER
WHILE (TIMER - start!) < delay: WEND
NEXT j
bin = bin + steps
SELECT CASE bin
CASE IS = 0
bin = 12
CASE IS = 13
bin = 1
CASE ELSE
END SELECT
LOCATE 10, 27: PRINT "TRAY CURRENTLY AT BIN: "; bin: SPACE$(2)
SOUND 625, 1
NEXT i
IF steps = -1 THEN
OUT add, a(lo)
ainit = a(lo)
ELSE
ainit = a(hi)
END IF
start! = TIMER
WHILE (TIMER - start!) < 1: WEND
OUT add, 0
abinold = abin
GOTO loop01
END
  
```

center of the tray. Obtain a 1/4-20 machine screw at least 1 1/2-inch long, and two 1/4-20 machine nuts. Thread

one nut on the screw and insert the screw into the drilled hole from the top of the tray. Now thread the other

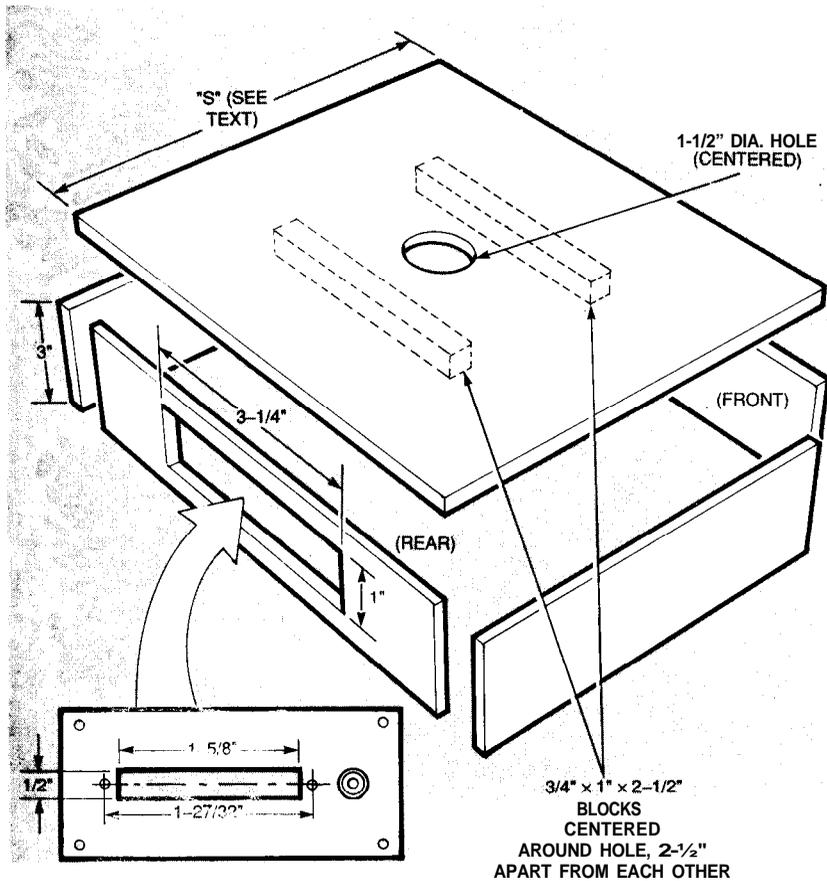


Fig. 8. One-half inch plywood serves well in building the case. The blocks on the underside hold the stepper motor, and the slot in the rear panel is for a mounting plate that connects power and the parallel port.

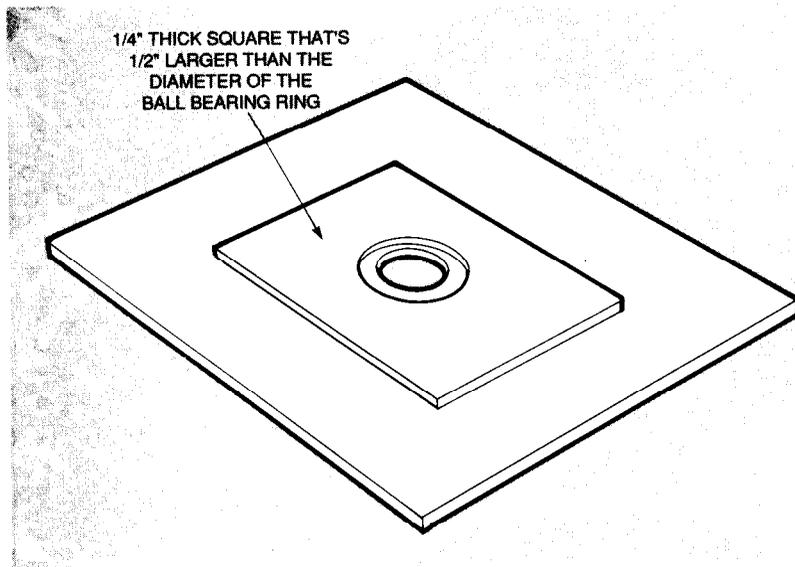


Fig. 9. The spacer provides clearance for the shaft-coupling mechanism.

nut onto the screw locking it in place. Do not tighten the nuts at this point, as the protruding length of the screw will be adjusted later.

The next task is to make the twelve bins. Figure 7 shows a pattern for one

bin. Note that all dimensions are constants, except the length, which is defined as $R - \frac{1}{4}$ -inch. Measure the inside diameter of the tray and divide by two to obtain the radius. For example, the author's prototype used a

10½-inch diameter tray, and $10\frac{1}{2} - \frac{1}{4} = 4.5$ -inches. You can make the bins from thin aluminum, wood, plastic, or other materials. An effective alternative is poster paper [commonly called "Oaktag" paper]. It's easy to work with, has the thickness of about five normal sheets of paper, and is stiff enough to hold the required bends.

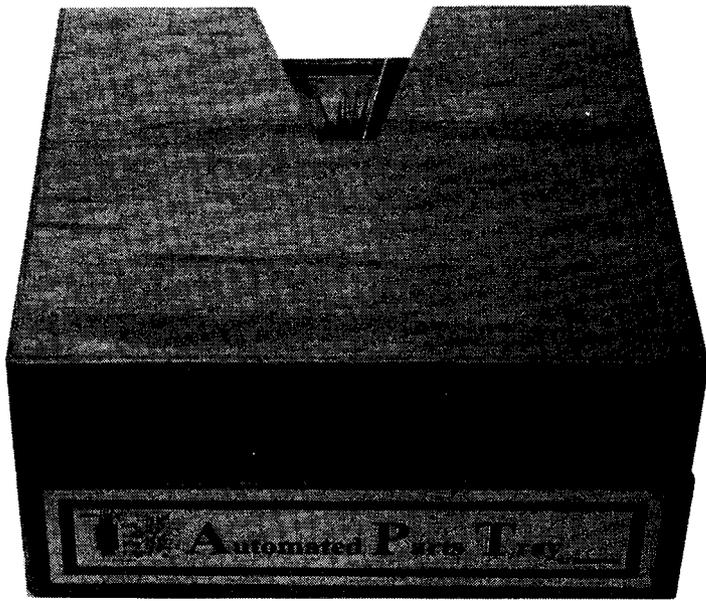
Using the length calculated for your tray, cut twelve blanks. Fold the four flaps upward, being careful to fold them straight and along the lines indicated on the pattern. Secure the tabs with transparent tape. When all twelve bins are complete, arrange them in a circle and secure them to one another where they meet with additional transparent tape. With careful assembly, the bins should fit snugly into the tray. However, an exact fit isn't necessary. The requirement is for twelve approximately equal bins in an assembly that won't rotate inside the inner lip of the tray.

Building the Case. Now we're ready to build the case. We used ½-inch plywood for our prototype. Form a square box with a closed top and an open bottom, as shown in Fig. 8. Side dimension S should be ½-inch larger than the outside diameter of the tray, plus twice the thickness of the material you're using for the case top cover. For example, with our 10½-inch tray and ½-inch plywood for the cover, $S = 10.5 + 0.5 + 2 \times 0.5 = 12$ inches.

A good material for the box top is ¼-inch luan mahogany plywood. Draw a line through diagonal corners and mark the point where the lines cross. Draw a line through the center perpendicular to the sides. Draw two parallel lines on either side of that one, each 1¼-inch from the first line. You should end up with two lines straddling the centerline of the top, and 2½-inches from each other.

Drill or otherwise form a 1X-inch hole at the center of the top. The actual diameter or shape is not critical, as long as the opening is at least 1 inch in diameter. Now prepare two ¾ x 1 x 2½-inch blocks. Attach the two blocks to the underside of the top and along the two parallel lines drawn previously. Screw or glue the blocks in place.

Measure the diameter of the ball-bearing assembly (BBA) shown in Fig. 5-b. Add ½-inch to that amount, and



Here's the software that makes our board-assembly system work, and an optical encoder to make sure it works perfectly.

JAMES J. BARBARELLO

Last time we built a PC-based stepper-motor controller, and an automated parts-dispensing system called the APT (Automated Parts Tray). This time, we'll present the format of the data file that specifies the parts to use in populating a PC board. Then we'll discuss the software (including a complete listing), and show how to use it to populate a sample PC board—the stepper-motor controller presented last time. As a bonus, we'll provide hardware and software details for adding an optical encoder that will allow your PC to sense when bin 1 of the APT is in place.

Data File Format. The APT data file is simply an ASCII text file that lists every part that is to be mounted on a board. The format of the file is shown in Listing 1. (Note: All listings contain line numbers for reference only. If you type a file in, do not enter the line numbers.) Line 1 of the data file provides a description of the board; the description is displayed at the bottom of the screen whenever the APT program is running. Line 2 provides the board's horizontal and vertical dimensions. All dimensions are in inches. Values in the data file should be separated by commas.

Line 3, which contains only a backslash ["\"], says to begin a new part. Following that is one line for every part hole. Each line contains three items: x and y coordinates, and a third value (polarity), which is normally 0, and should be set to 1 for the

key point of a polarized component. For example, the cathode of a diode, pin 1 of an IC, or the positive end of an electrolytic capacitor could be used to help ensure correct part orientation. Each part may have as many as 20 holes. For parts with more than 20 holes (such as a 40-pin IC), simply identify the perimeter holes that define the location and orientation of the part.

After the line of the last hole for the current part comes a line containing only an asterisk [***]. The following line contains a comment about the part, such as its name, its value, its placement, etc. The next line contains the bin number, and that completes the first part. The next line contains a backslash, which marks the beginning of the next part.

To see how this works in practice, let's examine a sample data file for the stepper-motor PC board, presented last time. Listing 2 shows an abbrevi-

ated version of the data file, and Fig. 1 shows the foil pattern. To help identify the x and y coordinates of each hole, we have overlaid a 0.1-inch x 0.1-inch grid on the pattern. The positive x direction may be opposite of what you expect. The reason is that the APT program displays things looking down on the component side of the board, but we have only the foil side to work with. You could work with a component side view, in which case x would increase in the positive direction from left to right.

The first set of hole coordinates (lines 4-12) is followed by a comment that indicates those are non-part holes. Typical of that variety would be mounting holes, or holes used for options that are not being installed. Here, the first two sets of coordinates are for the holes where J1 mounts. The last three are for the holes indicated (in the original article) as "Future Optical-Encoder Input," along with holes for ground and +5 volts. None of those holes will have a part inserted, so the bin number (following the asterisk) is zero. That tells the program to display the holes for reference purposes, but not to consider them as part holes, i.e., not to rotate the parts tray.

As shown in lines 13-27, the first part to be installed is J1. Note that 11 holes are specified, and the last hole is shown as the polarity indicator. That is followed by the asterisk separator, and a comment line. Since J1 is relatively heavy, the comment indicates that it should be obtained from sup-

LISTING 1

```
1. Board Description (79 characters max)
2. Board Dimensions {x, y}
3. Backslash (\)
4. x,y,p Part1 Hole1(horizontal, vertical,
   polarized (1 =yes))
5. x,y,p Part1 Hole2
   ..
n. x,y,p Part1 Hole n
n+1. *(Asterisk)
n+2. Part Description (79 characters max)
n-3. Bin Number (1-12, or 0 to skip)
n+4. Backslash (\)
n+5. x,y,p Part2 Hole1
   ...
```

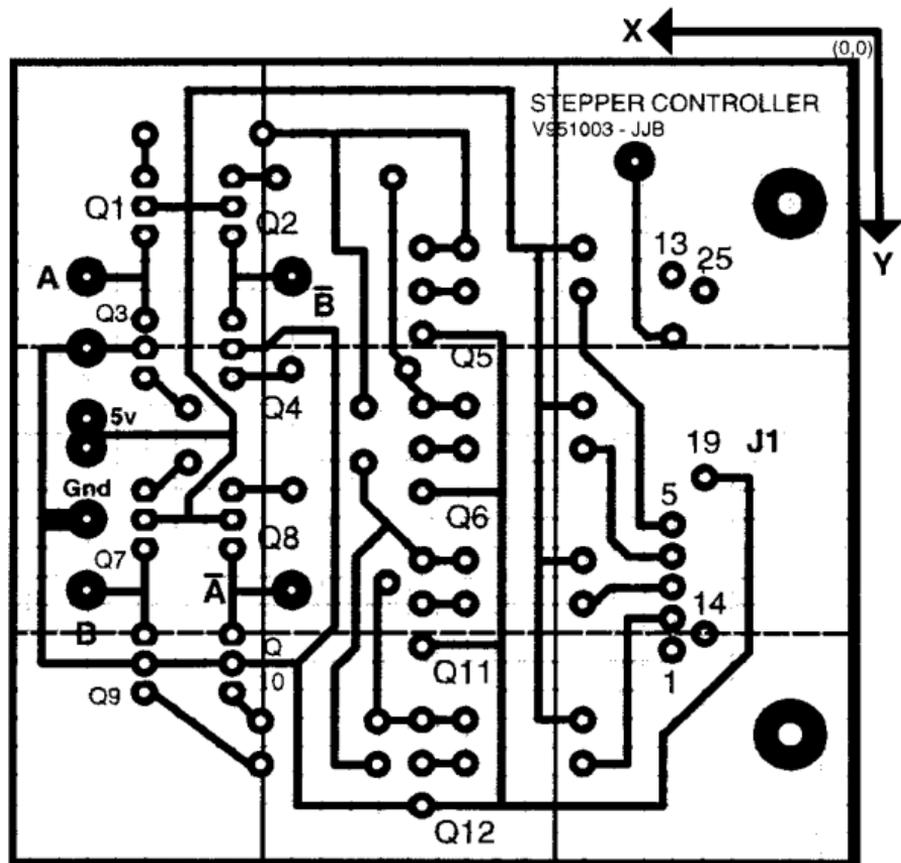


Fig. 1. Here's the foil-side view of the Stepper Motor Controller presented last time. The superimposed grid helps locate component positions accurately.

LISTING 2

001. STEPPER CONTROLLER,
V951003 - JJB

002. 2.85,2.8

003. \

004. .2,.5,0

005. .2,2.35,0

006. .7,.35,0

007. 2.6,1,0

008. 2.6,1.25,0

009. *

010. Non-Part Holes. Bin 0 means
skip as a part to be placed.

011. 0

012. \

013. .6,.75,0

014. .5,.8,0

015. .6,.95,0

016. .6,1.05,0

017. .5,1.45,0

018. .6,1.6,0

019. .6,1.73,0

020. .6,1.84,0

021. .5,2,0

022. .6,1.95,0

023. .6,2.07,1

024. *

025. J1 - DB25 Conn, Pin 1 Red.
GET FROM SUPPLEMENTARY
BIN A.

026. 1

027. \

...

100. .9,.8,0

101. 1.3,.8,0

102. *

103. R7 - 2.2Kohm

104. 2

105. \

...

208. 2.6,.75,0

209. *

210. STEPPER MOTOR PHASE A

211. 1

212. \

...

228. 2.6,1.3,1

229. 2.65,1.6,0

230. *

231. POWER - RED IS +5V,
WHITE IS GND

232. 1

232. \

LISTING 3

```

1 REM** STEPPER.BAS (c) 1995 JJ Barbarello,
   Manalapan, NJ (908) 536-5499
2 REM** V951013
3 DEF SEG = 64
4 DEFINT A: DIM a(4), h(500, 1), p(20, 1), comment$(500), bin(500)
5 abinold = 1: ainit = 12: OUT add, ainit
6 a(1) = 5: a(2) = 3: a(3) = 10: a(4) = 12
7 add = 888
8 OPEN "stepper.fil" FOR INPUT AS #1
9 LINE INPUT #1, file$: CLOSE 1
10 OPEN file$ FOR INPUT AS #1
11 LINE INPUT #1, title$
12 LINE INPUT #1, boardsize$
13 h(0, 0) = VAL(boardsize$)
14 comma = INSTR(boardsize$, ",")
15 h(0, 1) = VAL(MID$(boardsize$, comma + 1, 20))
16 REM***** READ SIZE OF PCB AND LOCATION OF HOLES
17 ctr1 = 1
18 WHILE NOT EOF(1)
19 LINE INPUT #1, a$: B$ = LEFT$(a$, 1)
20 SELECT CASE B$
21 CASE "0" TO "9", "-"
22 h(ctr1, 0) = VAL(a$)
23 comma1 = INSTR(a$, ",")
24 h(ctr1, 1) = VAL(MID$(a$, comma1 + 1, 20))
25 ctr1 = ctr1 + 1
26 CASE IS = ""
27 LINE INPUT #1, a$
28 comment$ = a$
29 LINE INPUT #1, a$
30 bin = VAL(a$)
31 CASE IS = "\"
32 CASE ELSE
33 END SELECT
34 WEND
35 REM** CLOSE & RE-OPEN FILE, DUMMY READ INITIAL DATA
36 CLOSE 1
37 OPEN file$ FOR INPUT AS #1
38 LINE INPUT #1, title$
39 LINE INPUT #1, boardsize$
40 LINE INPUT #1, backslash$
41 REM***** CALCULATE SCALE FACTORS FOR PCB DISPLAY
42 IF (h(0, 1) + 2) > h(0, 0) THEN
43 ystep = 28 / h(0, 1)
44 xstep = ystep * 7 / 5
45 adjust1:
46 IF (xstep * h(0, 0) * 10 > 540) OR (ystep * h(0, 1) * 10 > 280) THEN
47 ystep = ystep - .1: xstep = ystep * 7 / 5: GOTO adjust1
48 END IF
49 ELSE
50 xstep = 56 / h(0, 0)
51 ystep = xstep * .68
52 adjust2:
53 IF (xstep * h(0, 0) * 10 > 540) OR (ystep * h(0, 1) * 10 > 280) THEN
54 xstep = xstep - .1: ystep = xstep * .68: GOTO adjust2
55 END IF
56 END IF
57 REM***** START-UP SCREEN
58 SCREEN 9: CLS
59 LINE (3, 3)-(630, 335), 7, B: LINE (5, 5)-(627, 333), 7, B
60 LINE (230, 30)-(386, 65), 15, B
61 LOCATE 4, 35: COLOR 15, 9: PRINT "APT SYSTEM"
62 PAINT (235, 35), 9, 15: LOCATE 6, 18: COLOR 7, 1
63 PRINT "(c) 1995, JJ Barbarello, Manalapan, NJ 07726"
64 LOCATE 7, 33: PRINT "(908) 536-5499": COLOR 15, 1
65 LOCATE 13, 20: PRINT "Position Tray at Bin 1,
   then press Enter...";
66 OUT add, ainit
67 a$ = INPUT$(1)
68 REM***** WORK SCREEN
69 CLS
70 LINE (1, 1)-(630, 293), 3, BF
71 LINE (1, 1)-(630, 293), 7, B
72 LINE (1, 322)-(630, 334), 3, BF
73 LINE (1, 322)-(630, 334), 7, B
74 titleoffset = (80 - LEN(title$)) / 2
75 LOCATE 25, titleoffset: COLOR 8, 0: PRINT title$: : COLOR 15, 0
76 REM***** CALCULATE WORKING VARIABLES & DISPLAY PCB
77 x = h(0, 0) * 10 * xstep: y = h(0, 1) * 10 * ystep
78 xoffset = (620 - x) / 2: yoffset = (292 - y) / 2
79 LINE (xoffset - 4, yoffset - 2)-(xoffset + x + 4, yoffset + y + 8), 8, BF
80 FOR i = xoffset TO xstep * h(0, 0) * 10 + xoffset STEP xstep
81 FOR j = yoffset TO ystep * h(0, 1) * 10 + 2 + yoffset STEP ystep
82 PSET (i, j), 12
83 NEXT j
84 NEXT i
85 FOR i = 1 TO ctr1 - 1
86 CIRCLE (h(i, 0) * 10 * xstep + xoffset, h(i, 1) * 10 * ystep + yoffset), 1, 14
87 NEXT i
88 REM***** READ PART LOCATION DATA FROM FILE AND DISPLAY

```

```

89 hole = 1: partno = 1
90 WHILE NOT EOF(1)
91 LINE INPUT #1, a$: B$ = LEFT$(a$, 1)
92 SELECT CASE B$
93 CASE "0" TO "9", ".":
94 x = VAL(a$)
95 comma1 = INSTR(a$, ",")
96 comma2 = INSTR(comma1 + 1, a$, ",")
97 y = VAL(MID$(a$, comma1 + 1, comma2 - comma1 + 1))
98 positive = VAL(MID$(a$, comma2 + 1, LEN(a$) - comma2))
99 x = x * 10 * xstep + xoffset: y = y * 10 * ystep + yoffset
100 p(hole, 0) = x: p(hole, 1) = y: hole = hole + 1
101 IF positive = 1 THEN highlight = 12 ELSE highlight = 15
102 CIRCLE (x, y), 3, highlight
103 PAINT (x, y), highlight, highlight
104 CASE IS = ""
105 LINE INPUT #1, a$
106 comment$ = a$
107 LINE INPUT #1, a$
108 bin = VAL(a$)
109 LOCATE 22, 1: PRINT SPACE$(79);
110 LOCATE 23, 1: PRINT SPACE$(79);
111 LOCATE 22, 1: PRINT comment$
112 LOCATE 23, 1: COLOR 7, 0: PRINT "Part"; partno; "in BIN:"; bin;
    COLOR 15, 0
113 IF bin > 0 THEN GOSUB hwcontrol: a$ = INPUT$(1)
114 FOR i = 1 TO hole - 1
115 CIRCLE (p(i, 0), p(i, 1)), 3, 10
116 PAINT (p(i, 0), p(i, 1)), 8, 10
117 CIRCLE (p(i, 0), p(i, 1)), 3, 8
118 CIRCLE (p(i, 0), p(i, 1)), 1, 14
119 NEXT i
120 hole = 1
121 CASE IS = ""
122 IF bin > 0 THEN partno = partno + 1
123 CASE ELSE
124 END SELECT
125 WEND
126 SOUND 600, 1: SOUND 875, 2: SOUND 800, 2
127 bin = 1: GOSUB hwcontrol
128 SCREEN 0: CLS: LOCATE 10, 38: PRINT "Done"
129 LOCATE 18, 1
130 END
131 .....
132 REM** SUBROUTINE HWCONTROL
133 hwcontrol:

```

```

134 abin = bin
135 IF abin < 1 OR abin > 12 THEN ERROR 5
136 abin2 = abin
137 IF abin2 < abinold THEN abin2 = abin2 + 12
138 asteps = abin2 - abinold
139 SELECT CASE asteps
140 CASE 1 TO 6
141 lo = 1: hi = 4: steps = 1
142 CASE IS > 6
143 lo = 4: hi = 1: steps = -1: asteps = 12 - asteps
144 CASE IS < 0
145 lo = 4: hi = 1: steps = -1: asteps = -asteps
146 CASE ELSE
147 SOUND 675, 1: SOUND 500, 1
148 RETURN
149 END SELECT
150 OUT add, ainit
151 binold = abinold
152 FOR i = 1 TO asteps
153 FOR j = lo TO hi STEP steps
154 OUT add, a(j)
155 IF i > 1 AND i < asteps THEN delay = .075 ELSE delay = .125
156 START! = TIMER
157 WHILE (TIMER - START!) < delay: WEND
158 NEXT j
159 binold = binold + steps
160 SELECT CASE binold
161 CASE IS = 0
162 binold = 12
163 CASE IS = 13
164 binold = 1
165 CASE ELSE
166 END SELECT
167 NEXT i
168 IF steps = -1 THEN
169 OUT add, a(lo)
170 ainit = a(lo)
171 ELSE
172 ainit = a(hi)
173 END IF
174 START! = TIMER
175 WHILE (TIMER - START!) < 1: WEND
176 OUT add, 0
177 abinold = abin
178 SOUND 500, 1: SOUND 675, 1
179 RETURN

```

plementary bin A. However, the bin identifier is cited as 1. There's still no need to move the tray.

Bin 1 contains the 100-ohm resistors. When we need a new value (R7, 2.2K, lines 100-105), note that the bin number increases to "2." Parts identification continues until its time to attach the stepper-motor wires (lines 208-212). Here, only a single hole is identified, and the tray stays "parked" at bin 1. The file ends with the power connections [lines 228-232).

The APT Software. Now let's see how the software puts the data file to use. The program, STEPPER.BAS, is shown in Listing 3. (Line numbers are included for reference only. They must not be included in the run-time file). Lines 8 and 9 open a one-line file called STEPPER.FIL. That file contains the name of the text file that contains

the PC-board data. You can create the file using any text editor or from a DOS command line as follows:

```
C:APT>copy con stepper.fil  
      <Enter>  
datafile.txt <Enter>  
<Ctrl> <Z> <Enter>  
C:APT>
```

In the above, replace "datafile.txt" with the name of the file with the PC-board data that you created. The term <Enter> means press the Enter key. <Ctrl> <Z> means press and hold the **CTRL** key while you press the Z key.

The program then opens the PC-board data file and reads all the component location information [lines 10-40]. The program uses that information to calculate the scale at which the PC board will be displayed (42-56). The next step is to display

basic program information (57-75). Lines 77-87 then display the PC board. Note that the program runs in screen mode 9 (see line 58], which is a screen resolution of 640 x 350. Nearly all EGA VGA and SVGA adapters support that mode, but earlier adapters do not, so don't plan on using that old 8088-based PC you have lying around for this project unless it has an appropriate video adapter

Next, the program (lines 89-125) displays the holes associated with each part, calling subroutine HWCONTROL (from 113) to position the APT tray at the designated bin.

HWCONTROL. The purpose of HWCONTROL is to find the shortest route between the current and the next bin positions, and then move the tray to the new position.

HWCONTROL actually does three

TABLE 1—MOTION CONTROL SEQUENCE

Step	A(5)	B*(4)	B(3)	A*(2)	Decimal
1	1	0	1	0	10
2	0	0	1	1	3
3	0	1	0	1	5
4	1	1	0	0	12

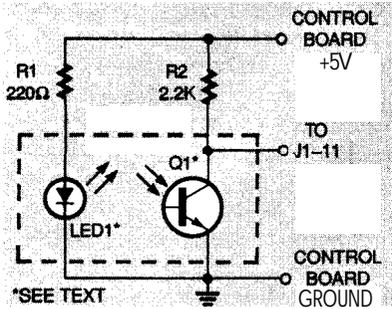


Fig. 2. The optical encoder consists of little more than an IR emitter and detector.

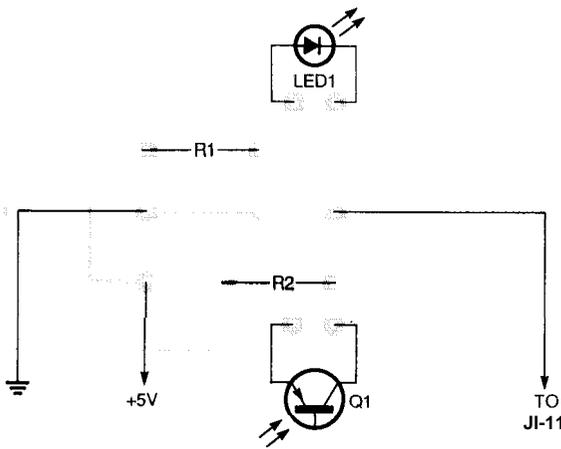


Fig. 3. Mount all components for the optical encoder board as shown here. Note that though shown off board, LED1 and Q1 are mounted as discussed in the text.

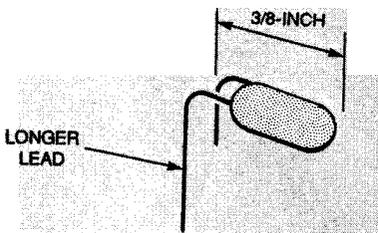


Fig. 4. Bend the leads of LED1 and Q1 to keep the bodies of those devices about a half-inch above the PC board.

things: It decides whether to move the tray, decides how to move the tray, and actually moves the tray. Table 1 shows the motion-control sequence. By performing steps 1-4 sequentially, the tray rotates clockwise [CW]. By performing the sequence backward (4-1), the tray rotates counterclockwise (CCW).

Line 134 saves the bin number to a temporary variable [abin]. Line 135 ensures that a valid bin number is being processed. Line 136 creates another copy (abin2) of the current bin number. Then, if the value of the new bin is less than the value of the last bin [i.e., the current tray position], line 137 adds 12 to abin2. To understand why, let's look at an example.

If we are at bin 6 (abinold = 6) and we want to go to bin 4 [abin2 = 4] we want to go backward two positions. So, adding 12 to abin2 gives 16. The

number of steps is thus $16 - 6 = 10$.

Now look at the SELECT CASE routine (139-149). If the number of steps we need to take is between one and six, we simply set up to rotate clockwise (CW) the specified number of steps. If we need to go more than six steps, we set up to go counterclockwise (CCW). Likewise, if the number of steps is less than zero, we also set up to go ccw.

In our example, line 143 does three things. First, it sets variable lo to 4 and hi to 1. Second, it sets the stepping value to - 1, so the For-Next loop will count backward. The result of the first two steps is CCW rotation. The result of the first two steps is CCW rotation. Third, it subtracts the current astep value [which is 10] from 12 to arrive at 2. As a result, the tray will move two steps CCW, from bin 6 to bin 4.

To continue the example, assume

we now want to move to bin 7. Line 137 does not come into play, since 7 is greater than 4. Line 138 calculates the difference as 3, which is handled in lines 140-141. The result is CW rotation, so the tray moves CW three positions to bin 7.

It's also worth pointing out that if the number of steps needed to change bins is zero, the CASE ELSE statement takes effect, so the routine returns without performing any action. That's important to remember when building the data file, since sequencing parts with identical values speeds up the assembly process.

All that's left now is to perform the actual motion. Line 150 outputs a decimal 12, which is always the start of the movement sequence. Then the For-Next loop (153-158) cycles through the four steps. Lines 155-157 provide a variable delay that allows the motor time to spin up the first time through the loop. Subsequently, a shorter delay suffices, thus speeding movement.

Lines 174-175 provide a one-second delay, after which line 176 sends a value of zero. The delay keeps the stepper energized to ensure that it

PARTS LIST FOR THE OPTICAL ENCODER

- Q1-Infrared detector, 940nm, T1 case (Jameco 112176 or equivalent)
- LED1--Infrared LED diode, T1 case (Jameco 112150 or equivalent)
- R1-220 ohms, 1/4-watt, 5% resistor
- R2-2200 ohms, 1/4-watt, 5% resistor
- Poster board, PC board, wire, mounting hardware, etc.

NOTE The following are available from James J. Barbarello, 817 Tennent Road, Manalapan, NJ 07726. PC Board: APT-PC (\$12.00). Software including source and executable code for all software in the series, sample data files, and an enhanced version of the APT software (including the optical encoder application): APT-S (\$12.00). All prices include shipping. International orders add \$5.00 (U.S. funds only). NJ residents must add sales tax. The author will accept phone calls 6-8:00 PM EST, Monday through Friday ONLY (Tel: 908-536-5499). The author will gladly answer written questions if accompanied by a self-addressed stamped envelope.

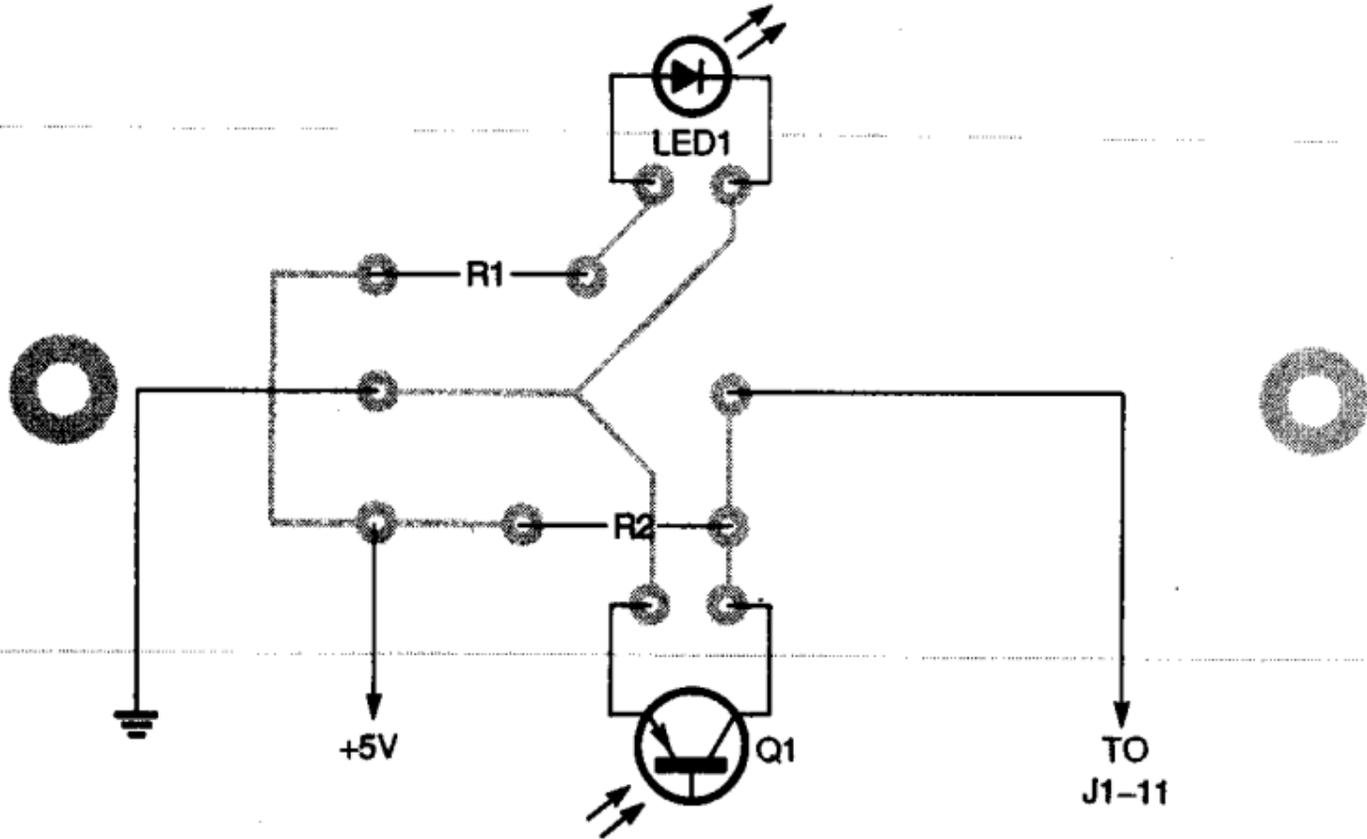


Fig. 3. Mount all components for the optical encoder board as shown here. Note that though shown off board, LED1 and Q1 are mounted as discussed in the text.

brakes properly. The zero then de-energizes the stepper. We could leave it energized, but if no further motion is

LISTING 4

```

1 REM** STEPFDBK.BAS
2 REM** V951014
3 CLS : DEF SEG = 64: add = 888
4 DIM a(4): a(1) = 5: a(2) = 3: a(3) = 10:
  a(4) = 12: ainit = 12
5 LOCATE 1, 25: PRINT "ALIGN
  OPTICAL ENCODER DISK"
6 LOCATE 3, 1: PRINT "Searching...";
7 startloop:
8 FOR j = 1 TO 4
9 OUT add, a(j)
10 IF (INP(add + 1) AND 128) / 128 = 1
  THEN GOTO foundbin1
11 start! = TIMER
12 WHILE (TIMER - start!) < .075: WEND
13 NEXT j
14 GOTO startloop
15 foundbin1:
16 OUT add, ainit
17 LOCATE 3, 1
18 PRINT "Rotate Disk So Aperture is
  Directly Under IR Diode."
19 PRINT "When Done, press Enter to
  Turn Off Stepper Motor...";
21 a$ = INPUT$(1)
22 OUT add, 0

```

needed in the near future, continuing to apply current will simply cause unnecessary heating of the coil. The last act of the subroutine is to record the current bin position (abin) as the previous bin position (abinold), in preparation for the next time through the loop.

Running the Software. To run the software, you need three things: STEPPER.BAS (an ASCII file containing the QBasic program), STEPPER.FIL (a file that contains the name of the data file), and a data file (e.g., STEPPER.DAT). You can create the files yourself, as shown in Listings 1, 2, and 3, or you can obtain them directly from the author, as discussed in the Parts List.

Next, connect the APT hardware to a power supply and parallel port. Run QBasic, load STEPPER.BAS, and run it. The program asks you to move the tray to bin position 1. Remove the APT's cover, and position the tray so bin 1 is accessible through the cutout. Reinstall the cover and press <Enter>.

The program then displays your PC board, highlighting each part in turn, and rotating the bin as necessary to provide access to the specified part. After the last part, the program de-energizes the stepper motor.

Now you're ready to create a data file for your own PC board. Go to it!

Optical Encoding. The current APT system is *open-loop*: We must assume that the tray moved to where we sent it, because the system provides no feedback to verify whether it did. A *closed-loop* system would provide such feedback. We're going to provide that feedback using optical encoding. Optical encoding is simply a way to sense rotational position using light.

The circuit is quite simple, as shown in Fig. 2. The collector of Q1 is normally high. When infrared (IR) energy hits the detector, it begins to conduct, so its collector goes low. By monitoring the state of Q1's collector, we can, under software control, say whether light is passing through or being blocked by a device. The device in this case happens to be a disc with a slit in it. The disc mounts concentric with the motor shaft, and the IR detector/emitter pair mount in such a way that the slit in the disc will pass between them as the motor rotates.

Parts alignment is somewhat critical, so we recommend the use of a PC board; a foil pattern accompanies this article. The parts-placement guide for that board appears in Fig. 3. The IR LED has a bluish lens, and the cathode is identified by a longer lead. You can verify that configuration by connecting the longer lead to +5-volts DC through a 220-ohm resistor, and connecting the shorter lead to ground. There should be about 1.2 volts across the diode. The detector has a clear lens, and the emitter is identified by a longer lead. Each device comes in a T1 package, which is just the right size for this application. A T1½ package would be too large.

Bend the IR devices as shown in Fig. 4, and install them on the PC board. Keep the component bodies about ½-inch above the plane of the PC board. Then install the two resistors and three wires for +5V, ground, and the output. The output wire connects to pin 11 of J1 on the original APT circuit.

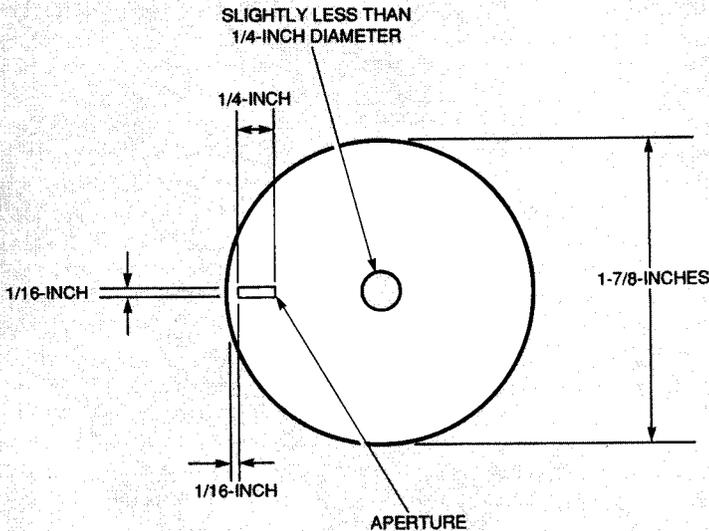


Fig. 5. The encoder disc must press-fit on the motor shaft, so be careful creating the center hole.

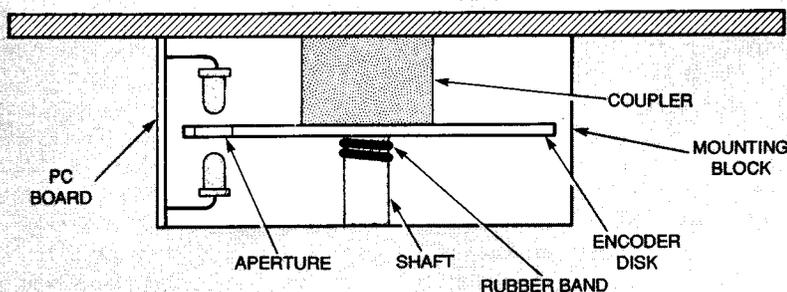


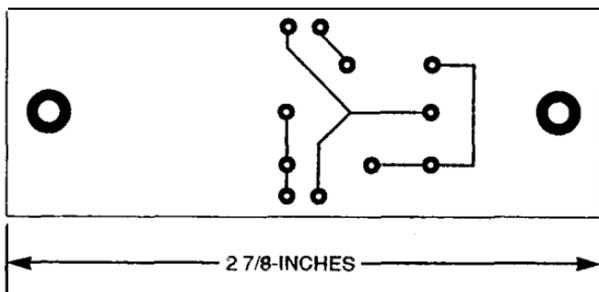
Fig. 6. Position the PC board so that the IR devices line up with the disc aperture between them.

You can make an encoder disc from poster paper or other stiff, thin material, as shown in Fig. 5. The diameter of the center hole should be slightly smaller than the shaft of the stepper motor. To mount the disc, remove the coupler on the stepper motor and loop a small rubber band around the shaft several times.

Referring to Fig. 6, push the encoder disc onto the shaft. The disc should have a firm press-fit, without bending or distorting. Reinstall the coupler and adjust the disc and the rubber band so that the disc rests directly against

routine. Line 10 senses when pin 11 of J1 goes low (input = 1), indicating that IR energy from the diode is passing through the aperture and pulling the detector's output low. Since the aperture could be detected during any of the four motion steps, line 16 repositions the stepper motor at the start of the sequence (ainit). The program then lets you align the aperture beneath the diode. Last, line 22 de-energizes the motor.

What's Next? There are several directions you could take if you wanted



Since parts alignment is fairly critical, use this PC board when building the optical encoder.

the bottom of the coupler and is held tight by the rubber band. Position the encoder PC board against the short ends of the blocks holding the stepper motor (shown last time), and adjust the positions of the IR emitter and detector so that they are close to the encoder disc and centered along the aperture in the disc. Secure the encoder PC board to the short ends of the blocks.

To test the circuit and align the disc, use the program shown in Listing 4. Connect the APT to your power supply and parallel port, but leave the tray off for now. Run the program and note that the encoder disc rotates. The disc should stop with the aperture directly between, or at least near, the IR devices. If it's directly under, you're done. Otherwise, rotate the disc slightly, as instructed by the program. In either case, press <Enter> to end the program. Move the shaft (not the disc) so the aperture is not under the diode and run the program again. Now the disc should stop with its aperture directly under the diode. After completing the alignment, reinstall the tray.

Let's take a quick look at the alignment program. Lines 7-16 form a loop that continually looks for the aperture. Within that loop, lines 8-13 constitute our old stepper-motor movement

to continue experimenting with stepper motors. For example, you could modify the program to include encoder-disc sensing. You could also modify the encoder disc to incorporate twelve apertures, one for each bin position.

A more ambitious project would be to use stepper motors to provide accurate X-Y positioning. In that way you could create an automated system for drilling PC boards with ease and precision. That will be our next project; look for it soon!