BOWLING GAME

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If your gameroom is too small for that full-size bowling alley you've always wanted, here is an electronics-based bowling game for you to try.

BOWLING MAY BE ONE OF OUR EARLIEST sports, with origins dating back to the Egyptians of 5200 BC. Almost five million Americans bowl in sanctioned leagues, and over sixty million more bowl for recreation or exercise. However, it is hard to find a functional yet reasonably priced toy bowling game for the home. The game described in this article can be built to almost any size, uses materials that are easily obtainable and priced reasonably and is a faithful representation of the real thing.

Playing the game

Depending on the size of the alley you want to build, various objects can be selected as a "ball" or puck. I chose to size everything around a quarter (a twenty-five cent coin), but you could use a poker chip or any other circular opaque object. When the game is turned on and reset, all 10 display LED's are dark. If the "ball" slides down the alley and passes over several of the "pin" spots the photo-Darlington transistors embedded in the lane are blocked from light. This change in state is remembered by the internal CMOS bistable latches, and the display LED's indicate which pins would have been knocked down in a real game had the ball taken a similar path. For example, striking the 1 and 2 pins but missing the 3 pin is the same as hitting the "pocket" and it gives you a strike. Hitting the 1, 2 and 3 pins results in that nemesis of all bowlers, the 7–10 split. Other ball paths are similarly translated into the equivalent pin knockdown. If you get a "spare," (i.e., less than 10 pins are knocked down), the second ball is then thrown. Again, the gating tells the display which pins have been knocked down. For more realism, all the spares can be picked up except for the 7–10 split, which is unmakable. After a strike or the second ball, pressing the RESET pushbutton clears the display for the next bowler. Scoring is done exactly as in real bowling; you can obtain bowling score sheets from a local bowling establishment.

The circuit

The block diagram in Fig. 1 shows the sequence that occurs when a ball or puck such as a quarter passes over the pin area of the board. Each of the front seven pin locations has a photo-Darlington transistor inserted in a slot flush with the lane surface. Normal room lighting is sufficient to cause logic-level switching when the photosensitive area is covered by the ball. Each phototransistor (Fig. 2) is wired to its own bistable latch circuit, which "remembers" a pass of the ball by flipping states. These latches, in turn, feed a series of CMOS AND gates (Fig. 3), which are wired to detect various pin combinations. A total of 30 gates in 10 IC packages is connected to provide 21 separate and distinct outputs. While there is no way to show the effect of a hook ball or a pin bouncing off the side boards, every possibility of one or two balls going over the pin area is considered. See Table 1 for the various input combinations and the resultant displays.

Twenty-one of the outputs are diode-Or'ed into a diode matrix ROM (*R*ead *O*nly *M*emory) with seven horizontal-input lines and 10 vertical-output lines (see Fig. 4). The input lines each have connecting diodes at the appropriate junctions of the output lines to drive the 10 display LED's.

The power supply for this circuit (Fig. 5) is noncritical since switching speed is not important. Any handy holder for 4 C or D batteries will suffice. I omitted the batteries and used a 6-volt calculator battery eliminator from my junk box instead. Diode D1, capacitor C1 and resistor R1 provide the needed rectification and protection against reverse polarity and power surges. Note that both supplies can be installed if a shorting-type jack is used; standard dry cells can leak or explode if charging is attempted. A battery eliminator of from 4.5 to 12 volts can be used if LED current-limiting resistors R20–R29 are changed in value; the CMOS IC's will function on any DC supply between 3 and 15 volts.

Construction

Before starting construction, decide on the size of the ball. I chose a quarter, since the alley is a convenient size for table-top play and there is no danger of losing the ball and not easily finding another. The dimensions shown in Fig. 6 for constructing the lane, gutters and phototransistor holes are all determined by the diameter of a quarter. If a different size "ball," such as a poker chip, is chosen, all these dimensions must be multiplied by the ratio of the diameter of

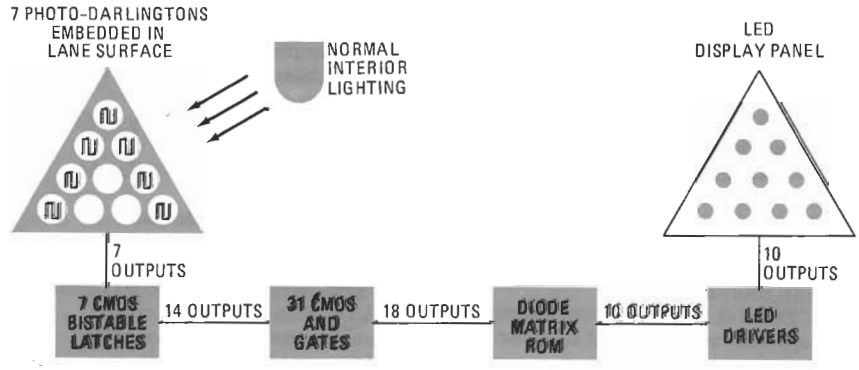


FIG. 1—BLOCK DIAGRAM of the bowling game. Action flows from pins at left to display at right.

the chosen ball to that of a quarter (this is approximately 15/16 inch). In addition, you must be careful to shape the circuit board (see Fig. 7) so that it fits under the alley.

While an etched PC board could have been developed for this project, the labor and cost involved would have exceeded that of the rest of the components combined. This game, with its low-cost IC's and relatively straightforward schematic diagram, is a natural for wire-wrapping techniques. I went one step farther and used a modification of the IC bricklaying method (see "IC Bricklaying," **Radio-Electronics,** December 1977). The IC's were glued upside down to a sheet of 1/8-inch clear plastic, and the pins were direct-wired using a wiring pencil. Anyone trying this, however, must accept the risk of static damage to the sensitive CMOS IC's. A safer procedure is to use multilevel wire-wrap sockets on perforated board and connect the pins with several colors of 30-gauge Kynar-insulated wire.

First, insert the sockets in their relative locations, being careful to leave room for mounting the hardware and other components (see Fig. 7 for general guidelines and dimensions). At this point, it is generally easiest to wire the positive and ground leads on all IC's, using 22-gauge hookup wire and soldering them flush with the PC board. This both holds the sockets in place and provides a pin reference. Note the nonstandard connections of IC's 15 and 16. Now, install R1 and R2 through R8, C1, D1 and the 22-gauge wires that will later be connected to S1, J1 and B1 (if used). Finally, label each socket and mark the pin 1 locations on *both* sides of the board.

Wiring between the pins of IC's 1–14 will be easier to perform and trace if one wire-insulation color is used for all the number-designated pins (1, $\overline{1}$, 2, etc.) and another color is used for all lettered pins A through FF. Start by connecting all the pins of each designation together, as shown in Fig. 8. For example, $\overline{1}$ (which means "not one") is found at IC1 pins 2

TABLE 1—INPUT-OUTPUT CODES

Pin Code	Gate Combinations	Gate Output	Diode Matrix Input Lines	Diode Matrix Outputs 1 2 3 4 5 6 7 8 9 10
1 $\overline{2}$ 3	B (1 $\overline{2}$ 3)	B	11, 14, 16	1 1 1 1 1 1 1 1 1 1
1 2 3	C (1 2 3)	C	11, 14, 16	1 1 1 1 1 1 1 1 1 1
1 2 3 $\overline{4}$ $\overline{6}$ $\overline{7}$ $\overline{10}$	A (1 2 3) & E ($\overline{4}$ $\overline{6}$ $\overline{7}$ $\overline{10}$)	N	11	1 1 1 1 1 1 0 1 1 0
$\overline{1}$ 3 $\overline{4}$	H ($\overline{1}$ $\overline{4}$) & 3	U	12	0 0 1 0 1 1 0 1 1 1
$\overline{3}$ $\overline{4}$ 6 $\overline{7}$ 10	M ($\overline{3}$ $\overline{4}$) & 6 $\overline{7}$ 10	T	13	0 0 0 0 0 1 0 0 1 1
$\overline{1}$ $\overline{4}$ $\overline{6}$ 10	H & L ($\overline{6}$ 10)	V	14	0 0 0 0 0 0 0 0 0 1
$\overline{2}$ 4 $\overline{6}$ 7 $\overline{10}$	J ($\overline{2}$ 4) & G ($\overline{6}$ 7) & $\overline{10}$	P	15	0 0 0 1 0 0 1 1 0 0
$\overline{1}$ $\overline{4}$ $\overline{6}$ 7	H & G	W	16	0 0 0 0 0 0 0 1 0 0
1 2 3 10	A & 10	X	11, 14	1 1 1 1 1 1 0 1 1 1
1 2 3 6	A & 6	Y	11, 14	1 1 1 1 1 1 0 1 1 1
$\overline{1}$ 2 3	K ($\overline{1}$ 2) & 3	Z	12, 17	0 1 1 1 1 1 1 1 1 1
$\overline{2}$ 3 4 6	J & 3 6	Q	12, 15	0 0 1 1 1 1 1 1 1 1
$\overline{1}$ 3 $\overline{4}$ 7	H & 3 7	R	12, 16	0 0 1 0 1 1 1 1 1 1
2 $\overline{3}$ 4 6	F (2 $\overline{3}$ 4 6)	F	13, 17	0 1 0 1 1 1 1 1 1 1
$\overline{2}$ 4 6 7 10	J & D (6 7 10)	AA	13, 15	0 0 0 1 0 1 1 1 1 1
$\overline{1}$ 2 $\overline{6}$	K & $\overline{6}$	BB	17	0 1 0 1 1 0 1 1 1 0
$\overline{2}$ 4 $\overline{6}$ 7 10	J & G & 10	S	14, 15	0 0 0 1 0 0 1 1 0 1
1 2 3 4	A & 4	CC	11, 16	1 1 1 1 1 1 1 1 1 0
1 2 3 7	A & 7	DD	11, 16	1 1 1 1 1 1 1 1 1 0
$\overline{3}$ $\overline{4}$ 6 7 10	M ($\overline{3}$ $\overline{4}$) & D	EE	13, 16	0 0 0 0 0 1 1 0 1 1
$\overline{1}$ 2 $\overline{6}$ 10	K & L	FF	14, 17	0 1 0 1 1 0 1 1 1 1

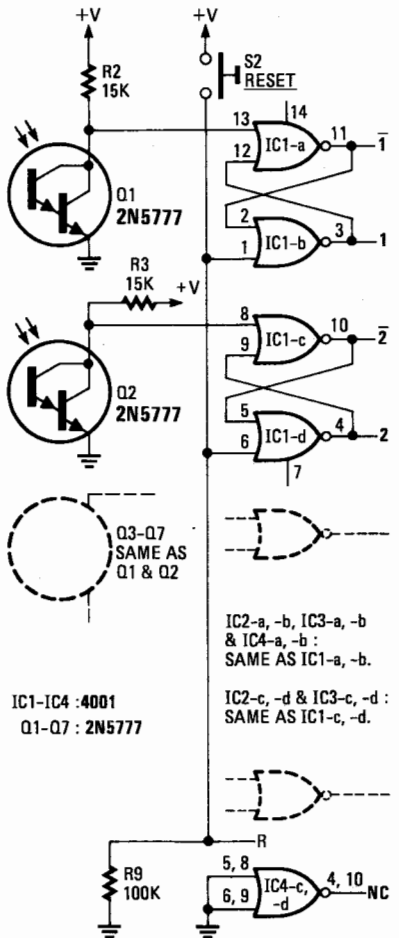
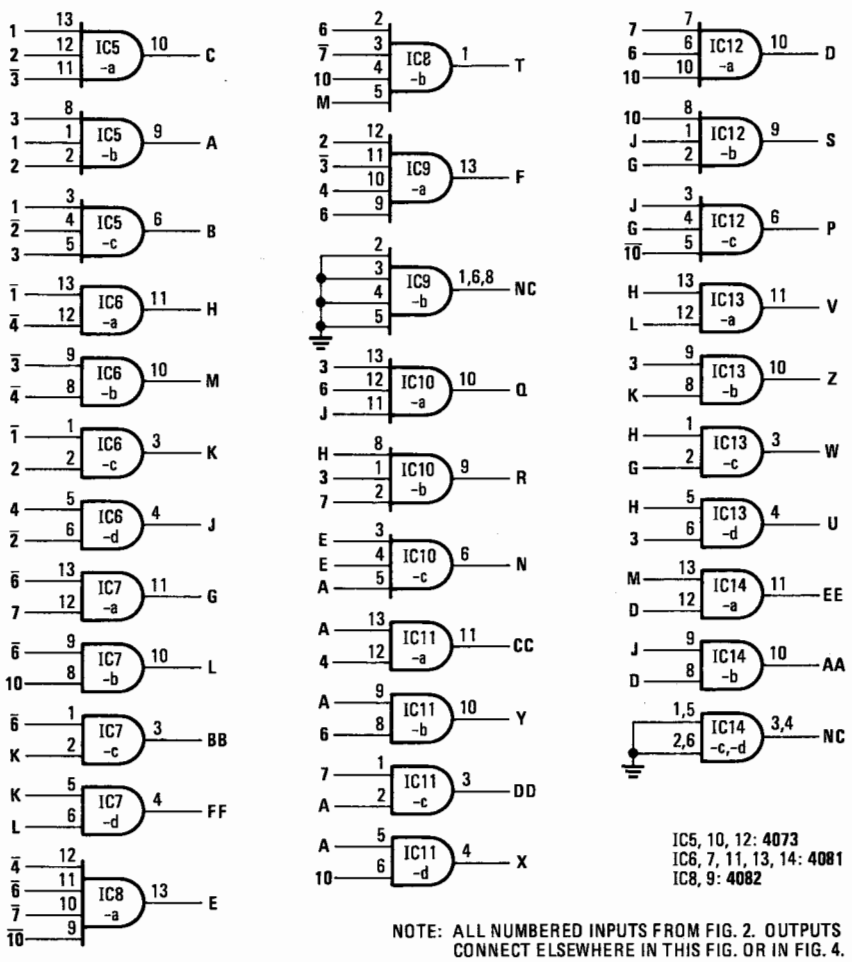
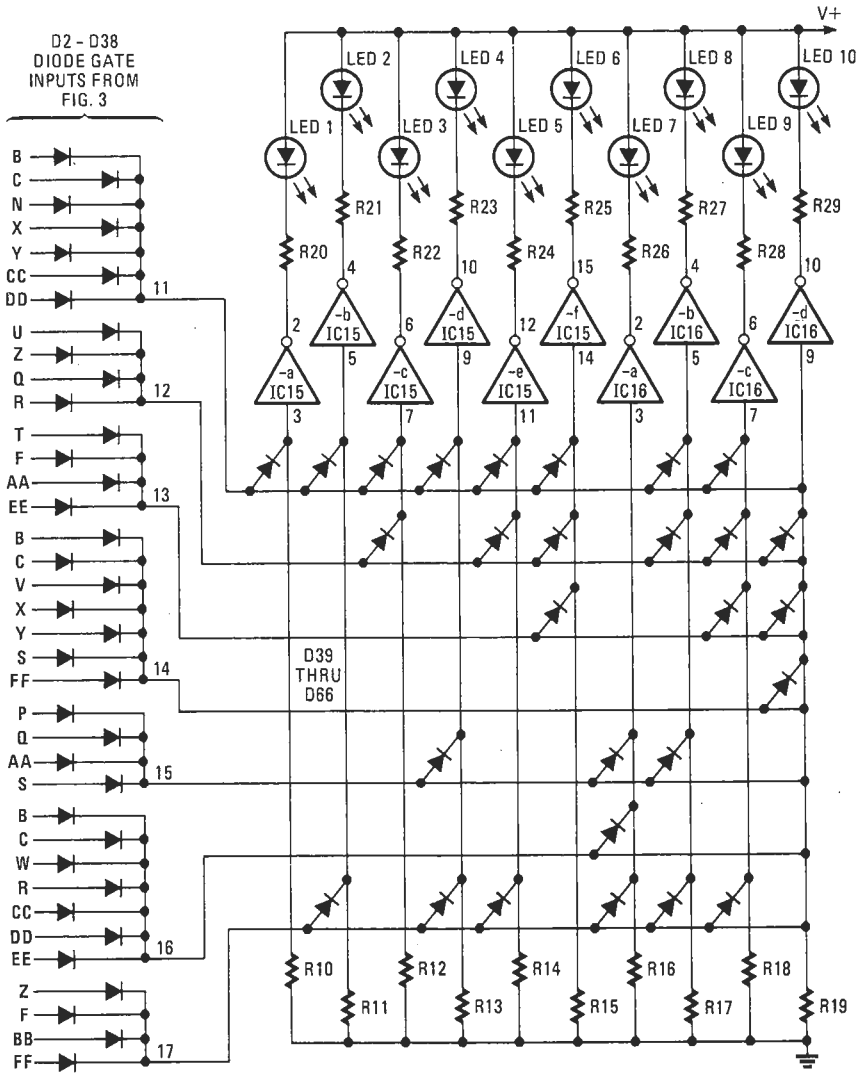


FIG. 2—DARLINGTON phototransistors Q–Q7 are wired to bistable latches using NOR gates.



NOTE: ALL NUMBERED INPUTS FROM FIG. 2. OUTPUTS CONNECT ELSEWHERE IN THIS FIG. OR IN FIG. 4.

FIG. 3—THIRTY AND GATES provide 21 outputs generated by input from the phototransistors.



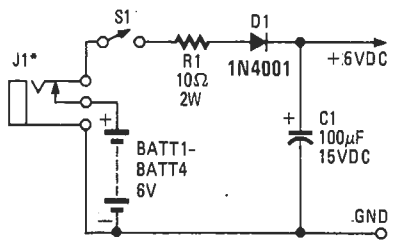
NOTES:

D2 - D66 = 1N914
R10 - R19 = 100K
R20 - R29 = 220 OHMS

IC15 = 4049
V+ : PIN 1.
GND : PIN 8.
NC : PINS 13 & 16.

IC16 = 4049
V+ : PIN 1.
GND : PINS 8, 11 & 14.
NC : PINS 12, 13, 15 & 16.

FIG. 4—DIODE OR GATES feed into a diode read-only-memory with seven horizontal input lines and ten vertical output lines. Ten invertersm fed by the output lines, control the LED indicators.



*SEE TEXT

FIG. 5—THE POWER SUPPLY. A 6-volt battery or four flashlight cells can be used away from AC lines. See text on AC input voltages.

and 11 and IC6 pins 1 and 13. Continue making pin connections until all numbered inputs have been checked off. Then, change wire colors and connect the pins with letter designations. Connect resistors R2–R8 to their respective leads on IC's 1 to 4 and to *V+* at the power supply. Also connect all the pins designated R to each other and to R9; ground the other end of R9.

The diode matrix and its inputs (see Fig. 4) come next. Diodes D2–D38 comprise a wired-OR circuit. Generally, the outputs of CMOS gates cannot be connected, since an off gate directly connected to an on gate would short the power-supply rails through the IC's. However, small-signal diodes can be used instead of additional gates to avoid this problem. Insert the bent leads of the diodes through the circuit board from the top with the anodes nearest the IC sockets. Then, connect the appropriate lettered outputs to their respective diodes.

Using a felt-tip pen, draw the horizontal matrix lines on the board and mark the locations of matrix diodes D39–D66. Insert the unbent anode leads through the board from the top. Run a piece of bare 22-gauge hookup wire from the cathodes of the groups of OR diodes across each line, wrapping once around each matrix diode. Solder snugly against the board so the diodes stand erect on the other side of the board. The 10 bias resistors, R10–R19, are similarly inserted from the top and wired in parallel to ground.

Now, turn the circuit board over and connect a wire up each of the 10 vertical lines of diodes, starting at the resistor. Thread these leads through the board and connect to their respective pins of IC's 15 and 16. Finally, connect the output pins of IC's 15 and 16 to resistors R20–R29.

Building the cabinet

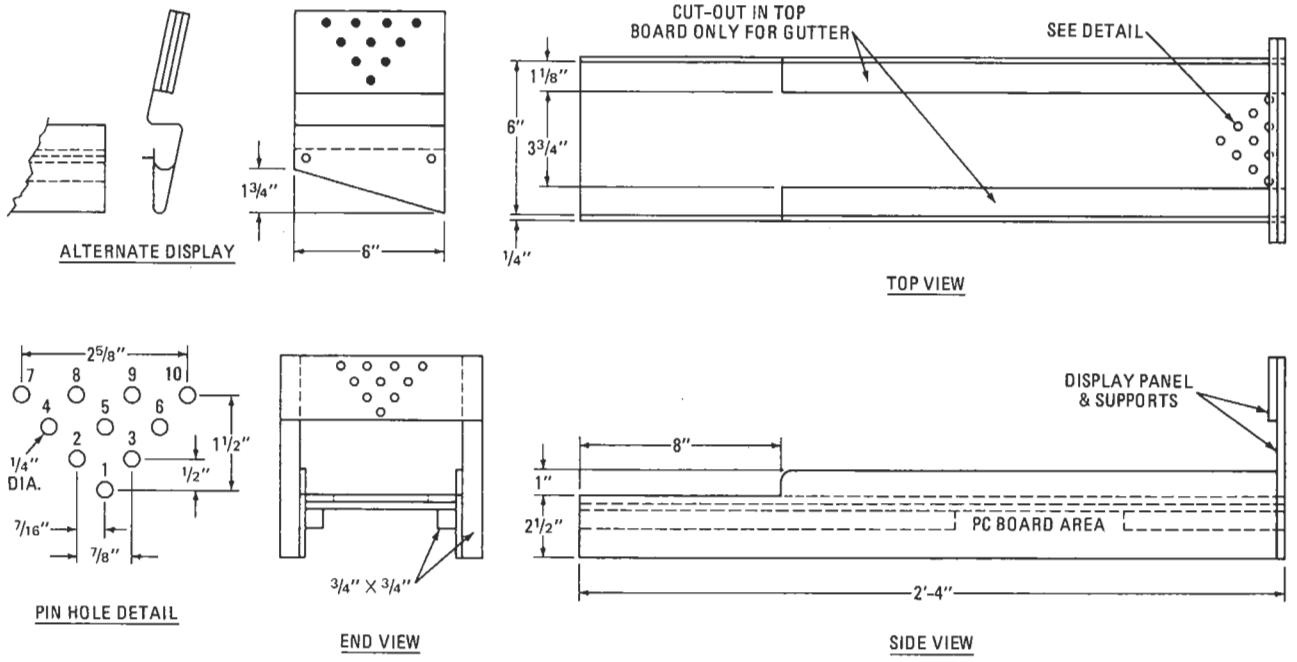
The construction of the alley is quite straightforward, requiring only simple hand tools, a few pieces of tempered *Masonite* or other smooth-surfaced board and some pine strips. First, cut both of the lane base pieces to the dimensions determined by the chosen ball size. Note that the T-shaped piece is the actual bowling surface and be careful not to mar or gouge it. Carefully mark and drill the photo-Darlington transistor mounting holes. Now, paint in a contrasting color the part of the bottom (rectangular) board that will be exposed as the gutters. Use black paint if a light shade of board is available, and white paint if you use dark *Masonite* or paneling. Do not paint the entire board because the glue will adhere better to bare wood or fiber. Next, glue the two pieces together.

When the lane is thoroughly dry, assemble it to the side boards using the ¾-inch or 1-inch-square corner braces and glue.

When all the glueing is complete and set, drill two very small holes (1/16 inch or less) through the bottom lane piece near the edge of each of the front seven transistor mounting holes. Snip off the base lead of photo-Darlington transistors

PARTS LIST

Resistors, ¼ watt, 10% unless otherwise noted
R1—10 ohms, 2 watts
R2–R8—15,000 ohms
R9–R19—100,000 ohms
R20–R29—220 ohms
C1—100 μF, 15 volts, electrolytic
D1—1N4001 or equal
D2–D66—1N914 small-signal diode
Q1–Q7—2N5777 photo-Darlington transistor
IC1–IC4—4001 quad 2-input NOR gate
IC5, IC10, IC12—4073 triple 3-input AND gate
IC6, IC7, IC11, IC13, IC14—quad 2-input AND gate
IC8, IC9—4082 dual 4-input AND gate
IC15, IC16—4049 inverting-type hex buffer/converters
LED1–LED10—jumbo red LED, Radio Shack 276-041 or equal
S1—SPST toggle or push-on/push-off switch
S2—SPST momentary pushbutton switch
J1—shorting-type phone jack, see text
BATT1–BATT4—size-C or size-D dry batteries, see text
Misc:
(14) 14-pin wire-wrap-type DIP sockets; (2) 16-pin DIP wire-wrap sockets; battery holder; perforated board; 22-gauge and 30-gauge wire; pressed board or *Masonite*, etc.



NOTE:
LED1-LED10 MOUNT IN PIN POSITIONS 1-10 RESPECTIVELY ON DISPLAY PANEL
PHOTOTRANSISTOR Q1 MOUNTS IN POSITION 1, Q2-P2, Q3-P3, Q4-P4, Q5-P6, Q6-P7, Q7-P10 ON ALLEY SURFACE

FIG. 6—SUGGESTED DIMENSIONS for the bowling alley. Pin hole spacings are for "ball" the size of a quarter. Alternate display mount has sloping "ball" return.

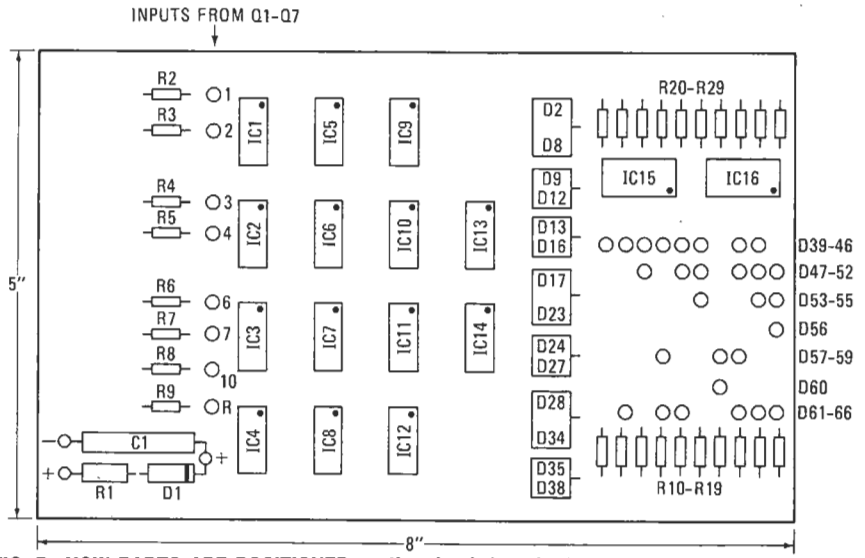
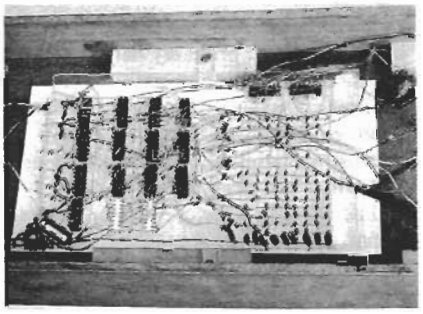


FIG. 7—HOW PARTS ARE POSITIONED on the circuit board. The transistors are cemented top-side-down so the pins are convenient for point-to-point wiring.



INTERIOR PHOTO showing circuit board of one version of the game. A PC board was not used because of circuit complexity.

Q1–Q7, carefully bend the other two leads as shown in Fig. 9, and insert them into the two small holes. Press down gently, making sure each transistor is slightly below the playing surface. Now, wire all the emitters in parallel and hook a separate lead to each collector. Leave these eight wires long enough so that they reach the eventual locations of R2–R8.

Constructing the display panel

The size of the display board is determined by the mounting method chosen. The simplest type of mounting is to attach the display panel to two vertical posts attached to the side frame pieces near the far end of the alley. In this case, the width of the panel will be the overall width of the alley plus the thicknesses of the vertical mounting posts (a 3/4-inch width is recommended). The actual display area is composed of two pieces of 1/8-inch or 3/16-inch particle board or *Masonite*. Drill two small holes (a maximum of 1/16 inch) at the location of each LED in the front piece, then paint the panel flat black. Insert the LED leads, hold the LED's flush and carefully bend the leads flat on the back of the panel. Wire all the anodes in parallel with a piece of 22-gauge hookup wire that is long enough to reach from the display to the circuit board. Then, connect a similar length of 30-gauge Kynar wire to each of the cathodes. Group all the wires together at a bottom corner of the panel, and bolt or screw the back-panel cover in place. This will both hide the wires and hold the LED's in place. Now, carefully strip the necessary length of outer insulation off a piece of coax or other available wire of the proper size, and use it as a sheath for the eleven leads between the panel and the circuit board.

For a more professional look, drill the proper size holes in a piece of clear acrylic plastic and add it to the front of the panel. It will enhance the display brightness and give a finished appearance. I formed a convoluted shape out of clear plastic to form both a front panel and a sloping ball return.

Installation and testing

First, insert all the IC's into their proper sockets, observing polarity and CMOS-handling procedures. Then, screw the corners of the PC board to the mounting blocks and install power jack J1 and switches S1 and S2. If batteries are used, mount the battery holder. Finally, connect the display, power and switch leads. Be very careful to observe polarity at jack J1 and the battery holder. Unless the display wires are color-coded or tagged, they will have to be sorted out one

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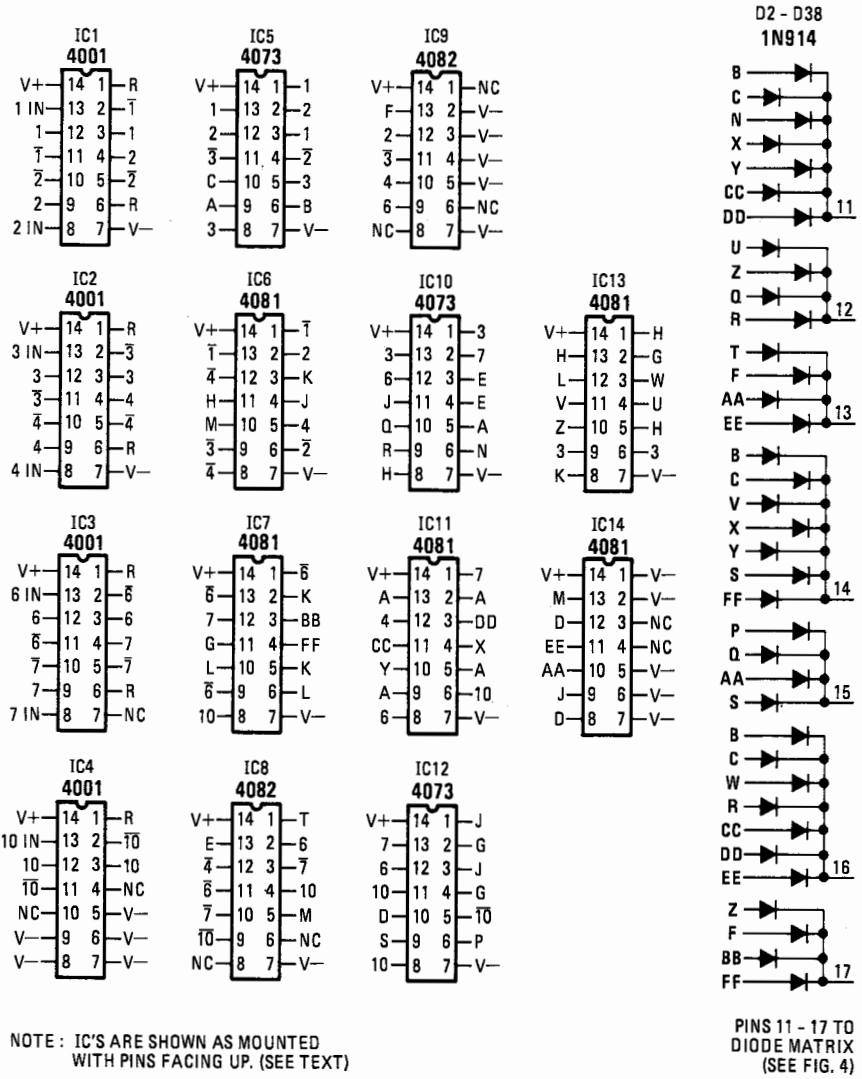
by one as they are attached to their respective resistors, R20–R29. Use a 6-volt supply with a 220-ohm resistor in series (or a 1.5-volt battery with a 100-ohm resistor) to individually light the LED's for identification. Attach the 22-gauge anode lead to the positive power supply. The RESET pushbutton, S2, connects to point "R" on IC's 1–4 and to the V+ line.

It is prudent to test the gating circuits before hooking up the photo-Darlington transistors. Apply power to the circuit and use test leads to connect each of the inputs to either ground or V+. Use a voltmeter or logic probe to follow each signal through the gates and into the diode matrix. If an error has been made, it can be traced and corrected in a matter of a few minutes. Try all the combinations shown in Table 1, checking each for the proper output.

Now, connect the photo-transistor leads to their appropriate points on IC's 1–4, apply a light source and selectively block each of the slots to make sure the voltage swing from light to dark is sufficient to trigger the CMOS latches. In general, the dark voltage at the junction of the collector, the resistor and the gate must be greater than 0.7 times the V+ voltage, and the lighted voltage should be less than 0.3 times the V+ voltage. If these voltages are too low, try decreasing the value of the pullup resistor. If they are too high, increase the value. If this doesn't work, replace the transistor. In tests of over 40 junk-box photo-Darlington transistors, 32 were usable with a pullup resistor value near 15K and with a 40-watt incandescent lamp 48 inches away. Normal room lighting is usually well above this level. **R-E**



NOTE: IC'S ARE SHOWN AS MOUNTED WITH PINS FACING UP. (SEE TEXT)

FIG. 8—WIRING GUIDE for the point-to-point connections between the IC's and the diode gates.

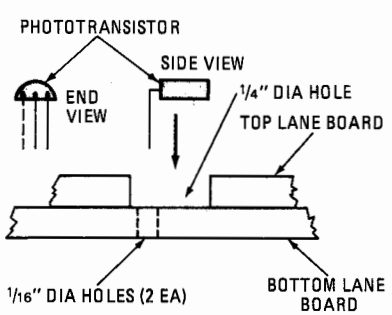


FIG. 9—HOW PHOTOTRANSISTORS are mounted. Be careful when bending pins.