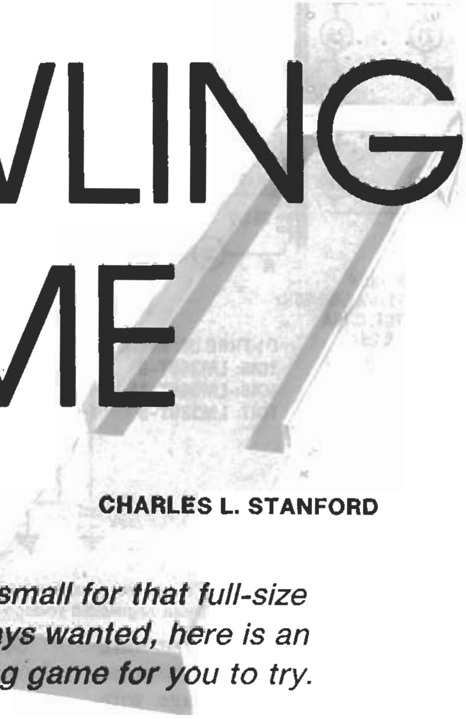
BOWLING GAME



CHARLES L. STANFORD

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

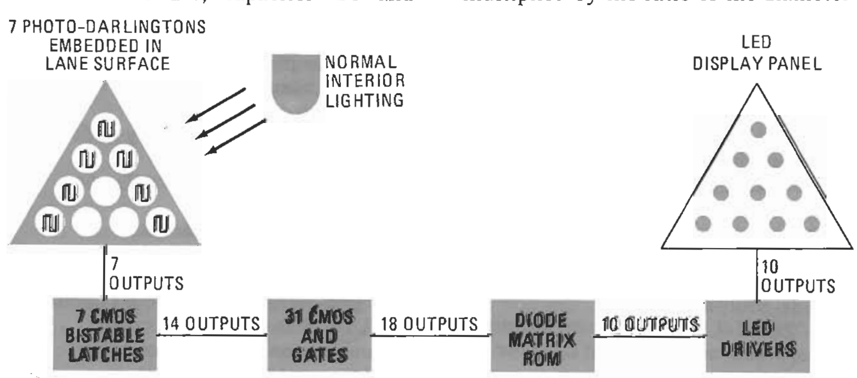


FIG. 1—BLOCK DIAGRAM of the bowling game. Action flows from pins at left to display at right.

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 $\overline{3}$	C (1 2 $\overline{3}$)	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 1 0 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

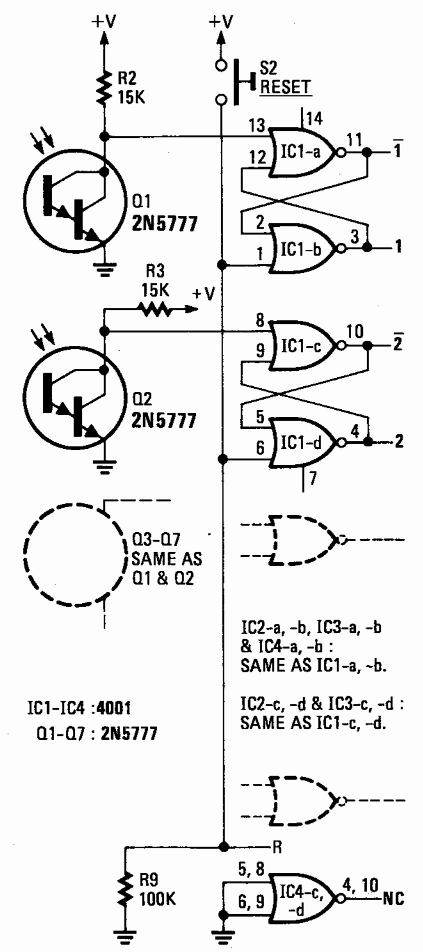


FIG. 2—DARLINGTON phototransistors Q-Q7 are wired to bistable latches using NOR gates.

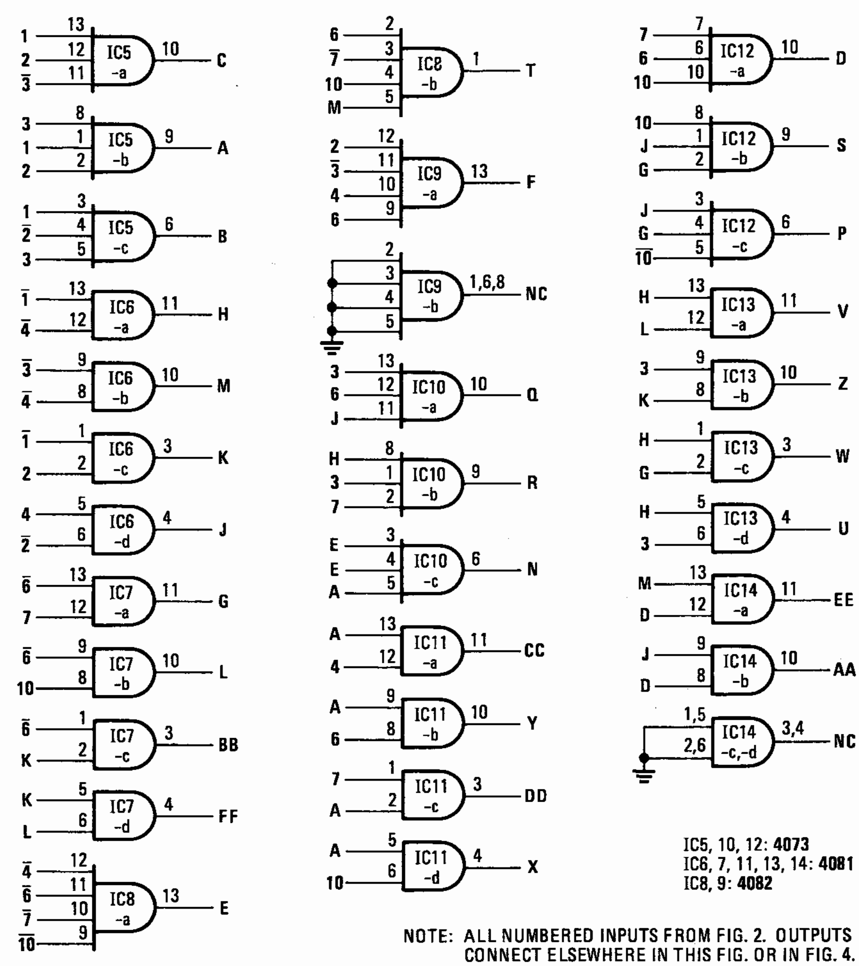
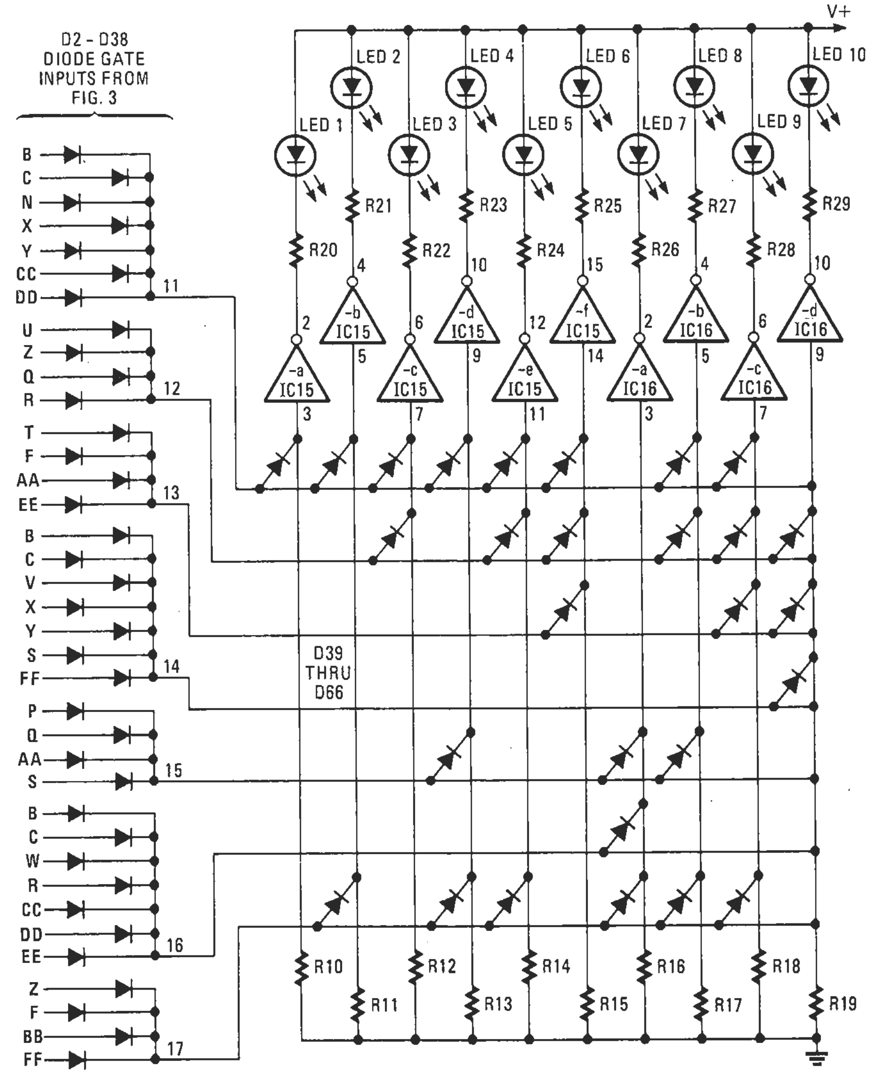


FIG. 3—THIRTY AND GATES provide 21 outputs generated by input from the phototransistors.



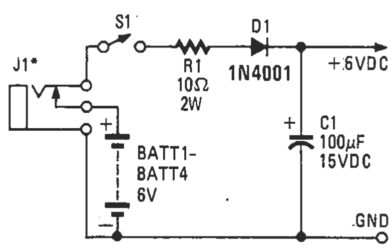
NOTES:

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

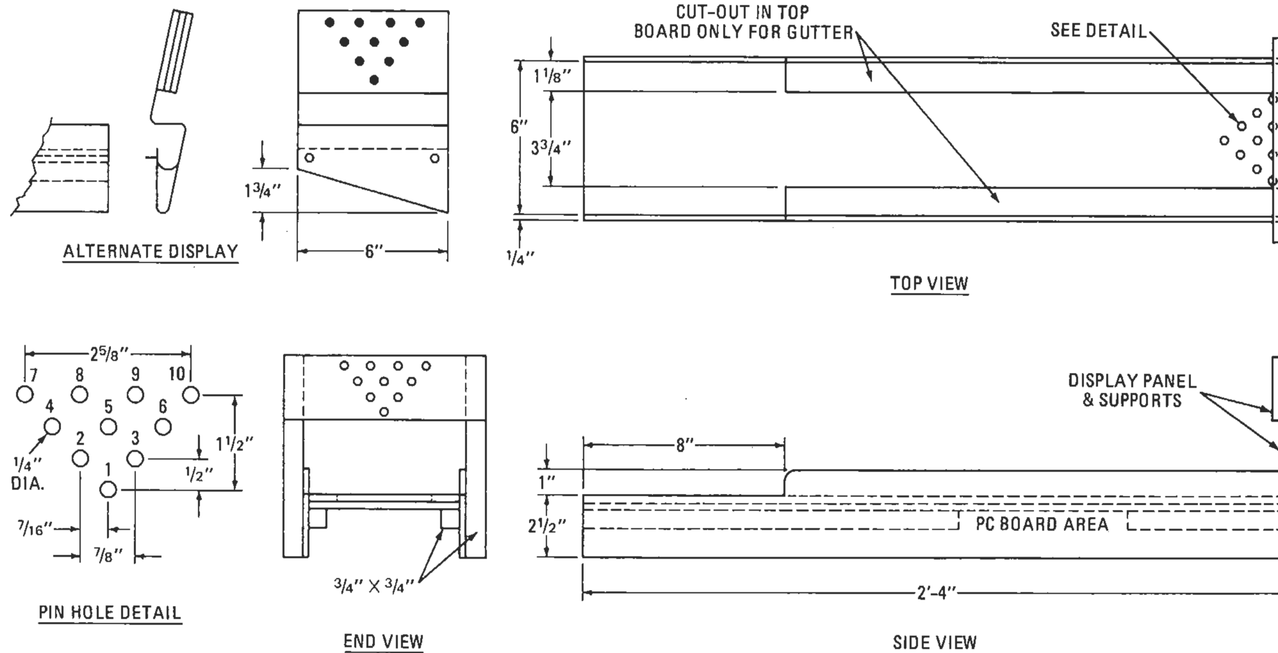
The construction of the alley is quite straightforward, requiring only simple hand tools, a few pieces of tempered *Masonite* or other smooth-surfaced board and some pine strips. First, cut both of the lane base pieces to the dimensions determined by the chosen ball size. Note that the T-shaped piece 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.

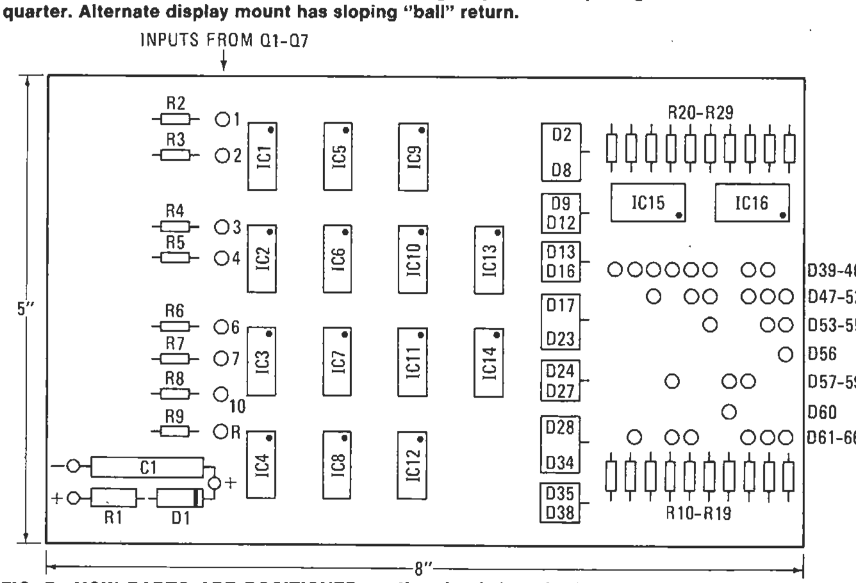
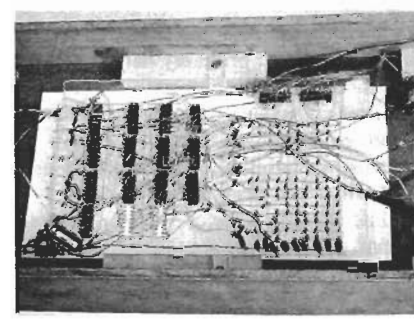


FIG. 7—HOW PARTS ARE POSITIONED on the circuit board. The transistors are cemented top-side-down so the pins are convenient for point-to-point wiring.



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 ¾-inch width is recommended). The actual display area is composed of two pieces of ⅛-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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BOWLING GAME
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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**

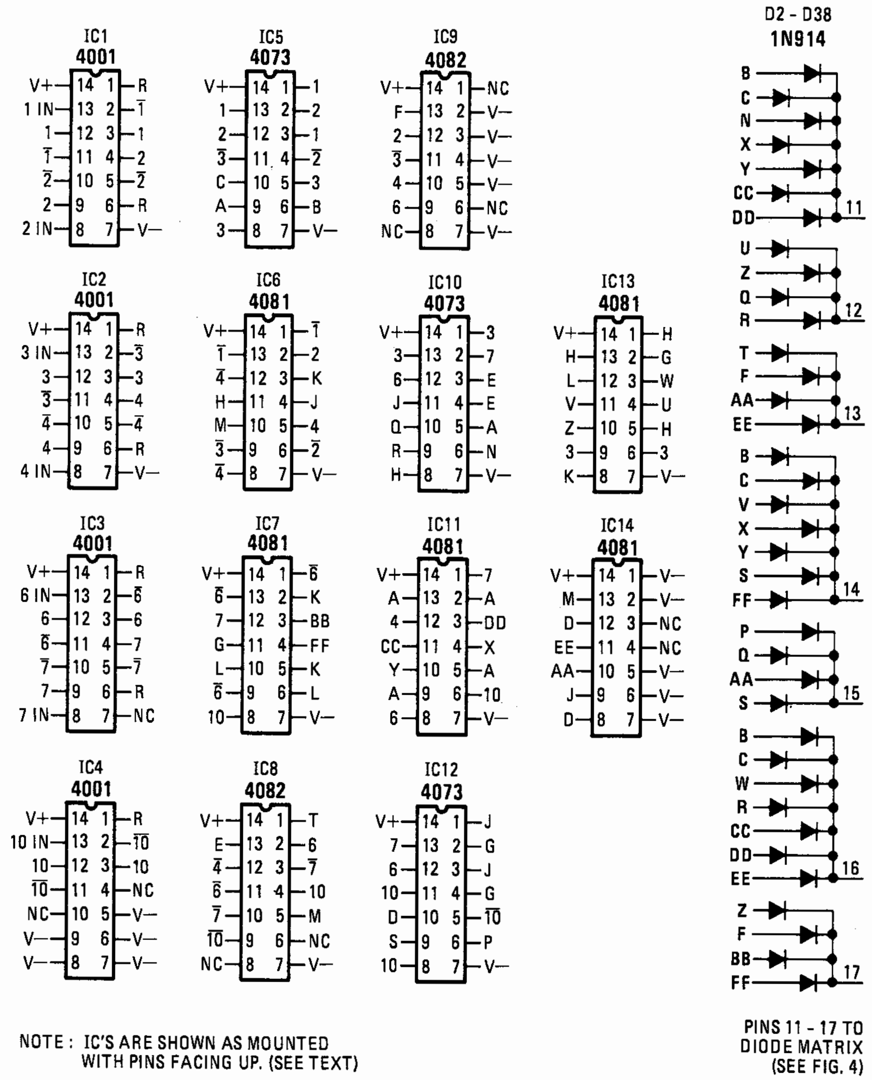


FIG. 8—WIRING GUIDE for the point-to-point connections between the IC's and the diode gates.

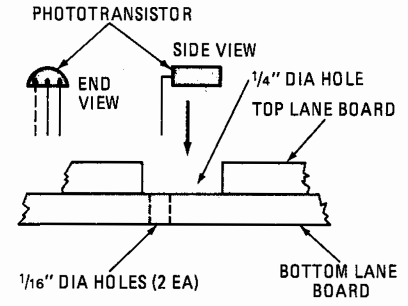
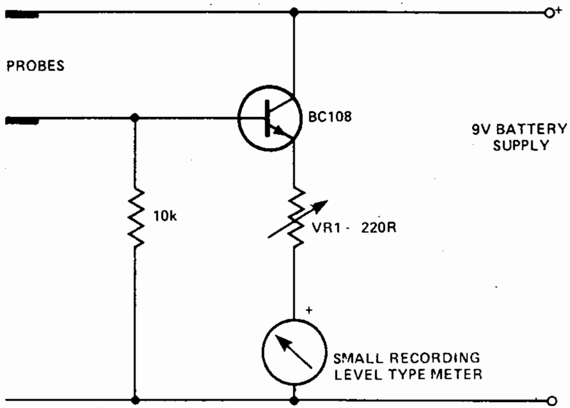


FIG. 9—HOW PHOTOTRANSISTORS are mounted. Be careful when bending pins.

SIMPLE 'TEST YOUR GRIP' CIRCUIT



As can be seen there is little that needs explaining but it should be noted that care should be exercised when using the unit. It is unsuitable for use with a battery eliminator due to the risk of mains shock as some of these units are incorrectly earthed.

The probes must have a fairly large surface area for the satisfactory operation of the device. Short (20cm.) lengths of *clean* copper pipe have been used with good results. VR1 is used to adjust the circuit to the age of the user; low for children, higher for adults. The meter may be replaced by a small LED and suitable series resistor.

LDR Protection. Some, like the ORP12, are a push-fit in soft plastic DIN plug cases and when they are so fitted form a watertight seal suitable for use outdoors. This method also neatens the appearance of the device and helps to stop the flow of complaints about nasty, ugly electronic gadgets. Before fitting the LDR the leads must of course be lengthened.

PUSH BUTTON DICE

We think this project will be a winner . . .

GENERATORS OF RANDOM NUMBERS in the range one to six (dice to most of us), are essential items in games ranging from Ludo to Backgammon. This is fortunate for those of us who count electronics amongst our hobbies. Why? you ask, well the answer's simple. When asked what your hobby is, if in reply you answer electronics, as often as not this will be greeted with a yawn, pictures of boring theory and mountains of test gear being conjured up by the questioner. Bring out an electronic game, however, and all this changes. Electronics can be fun.

Never Say Die

Unfortunately, most games, in order to be interesting, involve a lot of different factors that our electronics must keep track of. This, in terms of 'hardware' means lots of lamps, switches, and wire — complications. Happily, to build a dice, if our plans are followed, is an easy task, and will impress your friends as it is a distinct improvement over the traditional spotty blocks of wood.

Straight As A Die

Our photographs show that our die is built into a small box that has a line of Light Emitting Diodes (LEDs) to represent the six numbers plus a push button. Operating the button will activate the circuit and when the button is released one of the six LEDs will be lit, the particular one being impossible to predict. The LED will stay on for about five to ten seconds before going out. The dice is now ready to be "rolled" again.

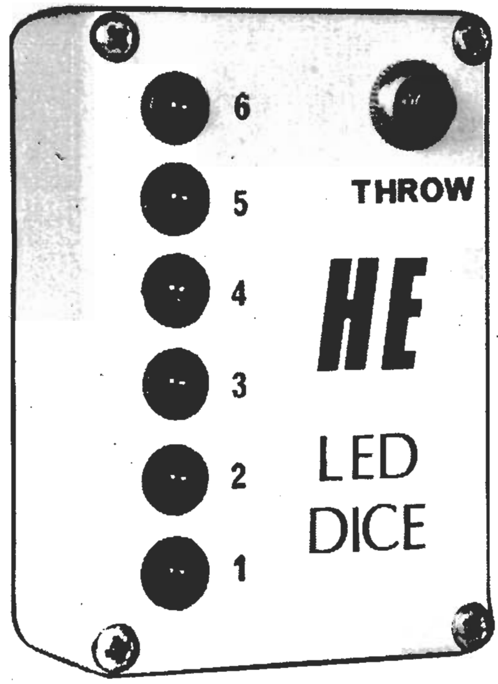
The dice does not have an on/off swich, as with the LEDs off the circuit draws such a small amount of current from the battery that such a switch is not necessary.

Construction

As with any project, the exact method of construction is largely a matter of personal choice. The photographs clearly show how our dice went together, but there is no reason why you should not put your project in a different type of case. At any rate the first thing to do is to assemble the PCB according to our overlay.

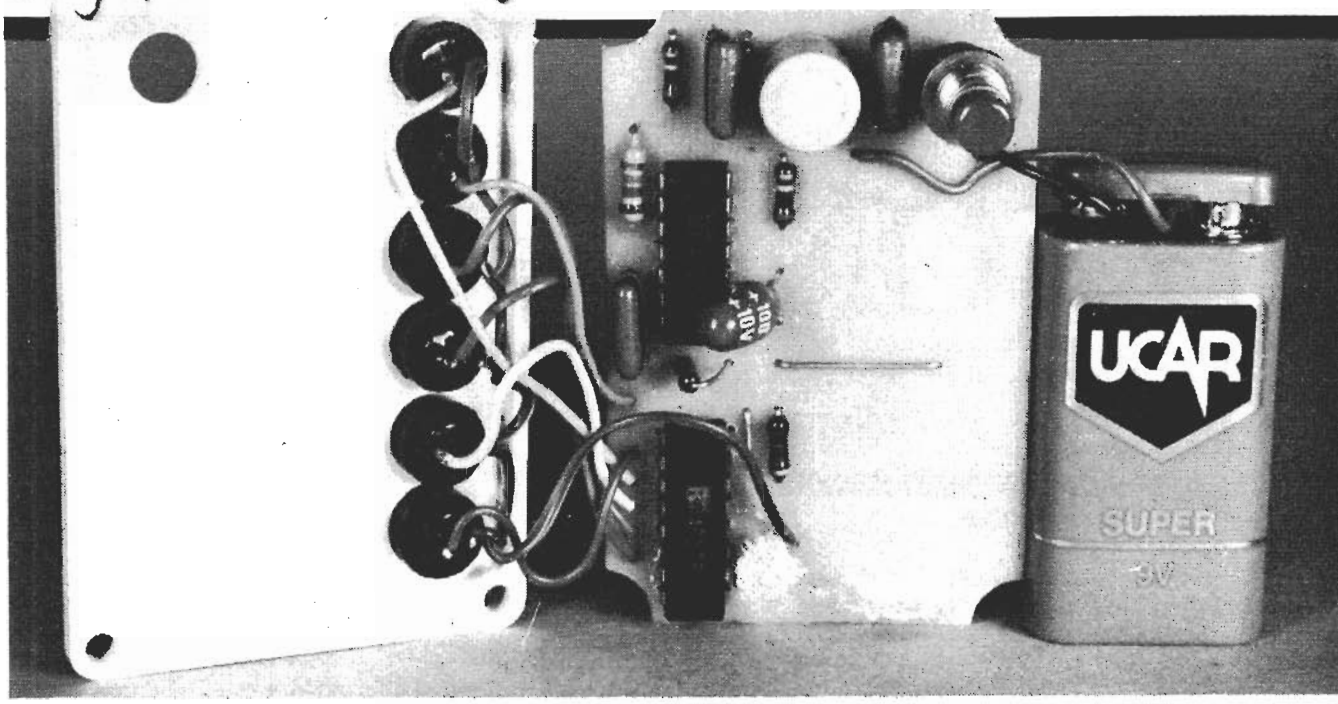
The dice uses a type of IC known as CMOS and for this reason we suggest that you use IC sockets when building the project as CMOS ICs are more electrically 'fragile' than other types of IC.

When mounting the components, make sure that the ICs and the electrolytic and tantalum capacitors are fitted

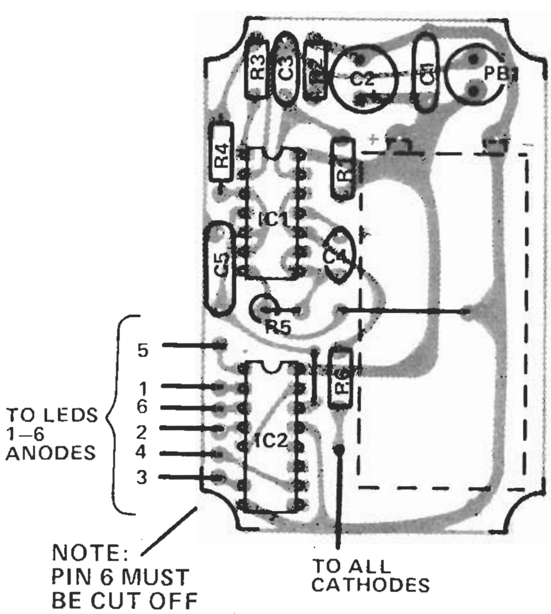


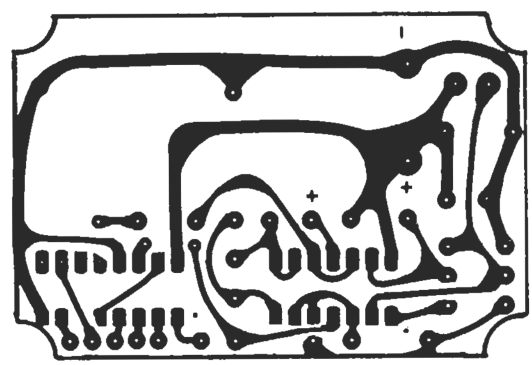
PARTS LIST

RESISTORS	(all ¼w 5%)	
R1, 3, 5	100k	
R2	10k	
R4	56k	
R6	470R	
CAPACITORS		
C1	100n	polyester
C2	100u	16V electrolytic
C3, 5	10n	polyester
C4	100u	10V tantalum
SEMICONDUCTORS		
IC1	CD4011B	
IC2	CD4017B	
LEDS 1-6	TIL209	
SWITCH		
PB1	Miniature push to make	
MISCELLANEOUS		
PCB as pattern, 9V battery plus clip, Vero box, wire, etc.		



ABOVE: the case opened to show what makes the dice tick. LEFT: the 'component overlay' which links the circuit diagram with the above photo. BELOW: the pattern for the copper foil side of the printed circuit board.





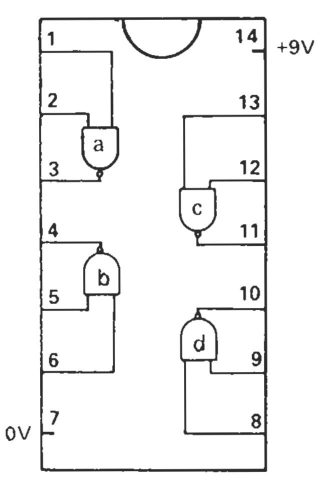
the right way round. Failure to do so will result in a dead LED dice.

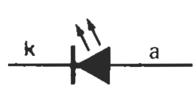
When marking out the front panel take care that the LEDs are in a straight line. The LEDs are mounted with special mounting clips that should be available from the people who supply the LEDs themselves.

There is a fair bit of wiring to do so take care when doing this job. It's easy to make a mistake here, and any error can take a long time to find.

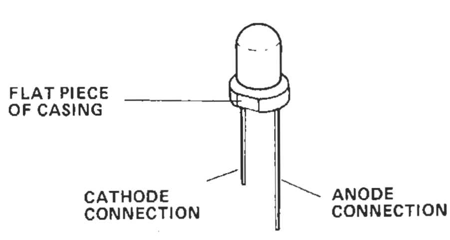
When all construction is complete, fit the battery and get ready to roll your first electronic die.●

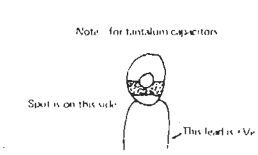
Below: Pin out data for IC1 and LEDs 1-6.



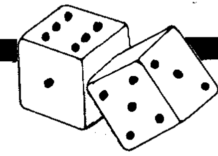


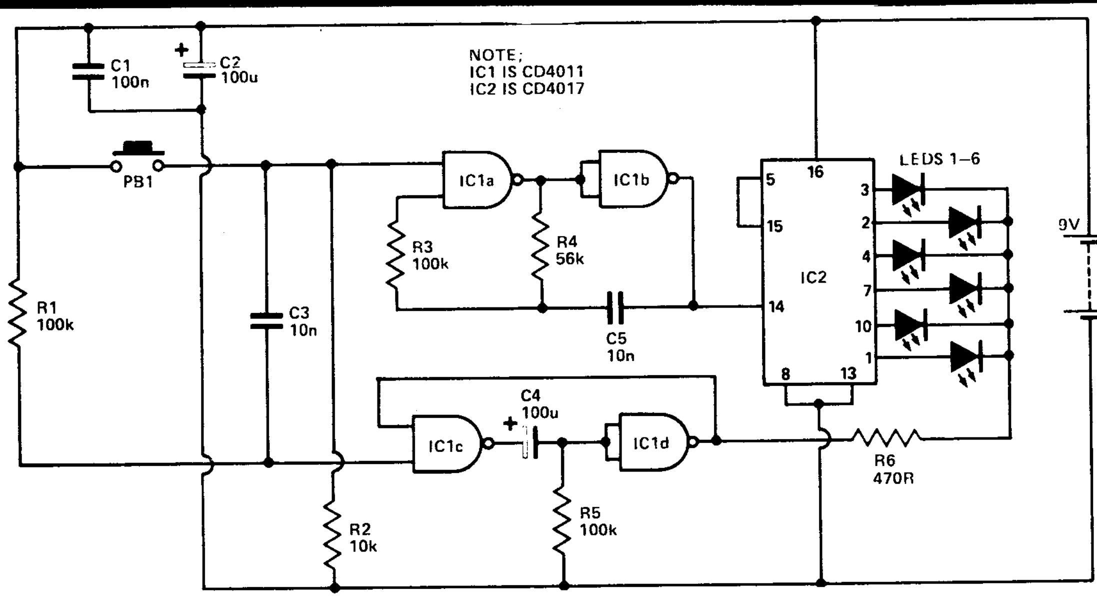
a = ANODE
k = CATHODE





ABOVE: some tantalum capacitors are not marked with a "+" as in the photo. They instead have a dot on one side only.





The circuit diagram

HOW IT WORKS

THE digital dice, in order to simulate the action of a real die, is required to "stop" with one of the circuit's six light-emitting diodes (LEDs) lit, each LED corresponding to one of the six numbers on the faces of the real die. To do this, it quickly turns each LED on in sequence when the start button is pressed, stopping with one LED on when the button is released. Because the circuit cycles through the sequence very quickly it is not possible to cheat by waiting for a particular LED to light and release the button at this point!

The circuit can be broken down into two sections, one dealing with the display and the other with timing and control signals. The latter are provided by two 'classic' circuit building blocks, namely the 'astable' formed by IC1a and IC1b and the 'monostable' configuration of IC1c and IC1d.

Each circuit is formed from two out of the four logic gates of IC1. The inputs of the logic gate can be in one of two conditions. They can either be 'low' (that is, near O V), or 'high'(near to the supply voltage, 9V in this case). The output of the gate can also adopt only these two values, the choice being determined by the state of the inputs. In this case as the gates are 'NAND' gates the output will be high at all times except when both the inputs are high at which point the output will go low. 'NAND' stands for 'not-and', the output being low whenever both one input 'and' the other are high.

The astable will not function until the start button takes one of IC1a's inputs high. At this point the output of IC1b will oscillate between 0V and 9V. The circuit is referred to as an astable (meaning 'not stable') because the output can assume these two conditions but is stable in neither.

A detailed description of the circuit would take up too much room but briefly the oscillator works like this: Suppose the output of IC1a is low and that as one of this gates' inputs is 'tied' high the other, connected to R3, must also be high. The junction of R3, R4 and C5 is thus high, but as R4 goes to the output of IC1a, which is low, the charge on C5 will leak away. At some point the voltage at this junction, having fallen to near the 0V rail, will cause the output of IC1a to go high and that of IC1/b to go low. C5 will now charge up via R4 which will in turn cause the circuit to assume its original state.

The series of pulses generated by the astable is fed to IC2. This is a counter IC, having ten outputs. As the pulses are fed to its input, each of the ten outputs will be turned on in sequence. For this circuit, however, we only want the IC to count up to six. To achieve this we connect the seventh output of IC2 to another of the IC's inputs called the 'reset' pin. When this pin is taken high it resets the counter back to the start. We now have our count of six.

The outputs of IC2 are taken to LEDs 1-6. LEDs are like ordinary diodes in that they will only pass current in one direction, but in addition when they are passing current will emit light. When an output of IC2 is high the associated LED will emit light if the common point to which the LEDs are taken, R6, is low.

R6 is taken to the output of IC1d. This point is normally high and thus the LEDs are all off. When the start button is released, however, the input of IC1c, junction of C3 and R1, goes low for a brief period of time and causes the output of this gate to go high. C4 'couples' this change to the input of IC1d and causes the output this gate to go low, activating the display and, by virtue of the fact that the output is also connected to IC1c, maintaining the high on the output of this gate. The charge on C4 will leak away, however, via R5 – and cause the circuit to assume the previous state after several seconds. This circuit is termed a monostable because it has two possible states, only one of which is stable (mono = one). It is necessary to include R6 in the circuit because the current passed by the LEDs must be limited to a safe value.

C2 and C1 are included to 'decouple' the supply that is, remove any fluctuations in the supply voltage that might upset circuit action.

HEADS OR TAILS

THE MULTIVIBRATOR IS ONE OF the most commonly-used circuit blocks in electronics – especially in digital circuitry. And the multivibrator forms the basis of this 'head or tails' project.

The multivibrator is a basic form of square-wave oscillator which in our design runs at about 700Hz whenever the push-button is pressed. When the button is released the oscillator will stop and the circuit will assume one of the two possible stable states. Either Q1 will be conducting and Q2 will be cut off, or Q2 will be conducting and Q1 will be cut off. Whichever transistor is conducting draws enough current down through the resistor and the light-emitting diode (in series with its collector) to cause the LED to light.

Notice that the circuit is symmetrical and that the two transistors are cross-coupled between their collectors and bases (via R3, C1 and R4, C2). If corresponding components on each side are matched there is equal probability of either transistor being on

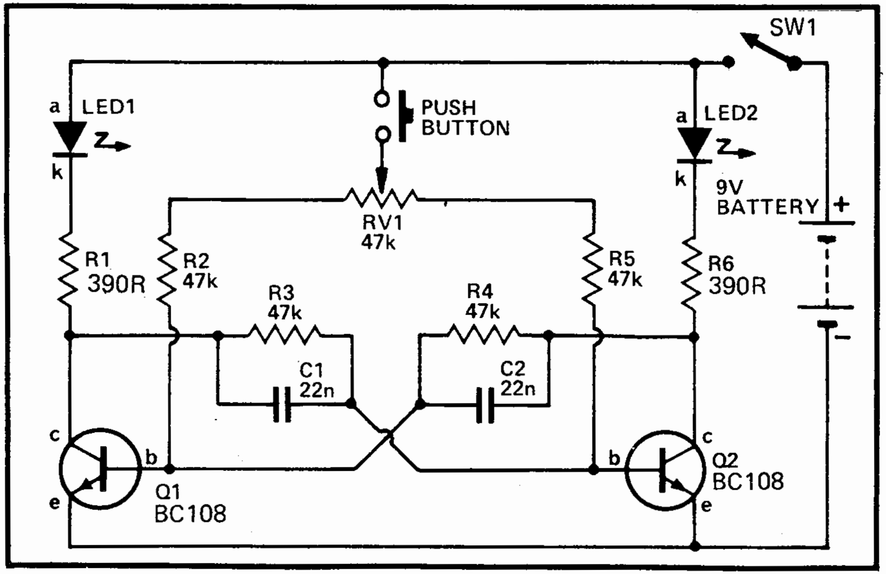
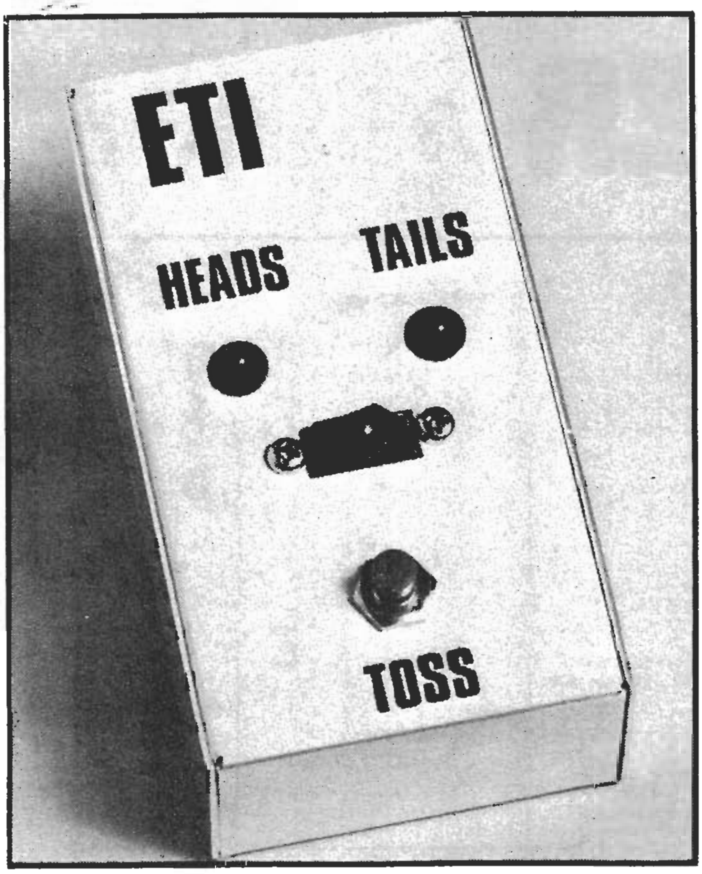
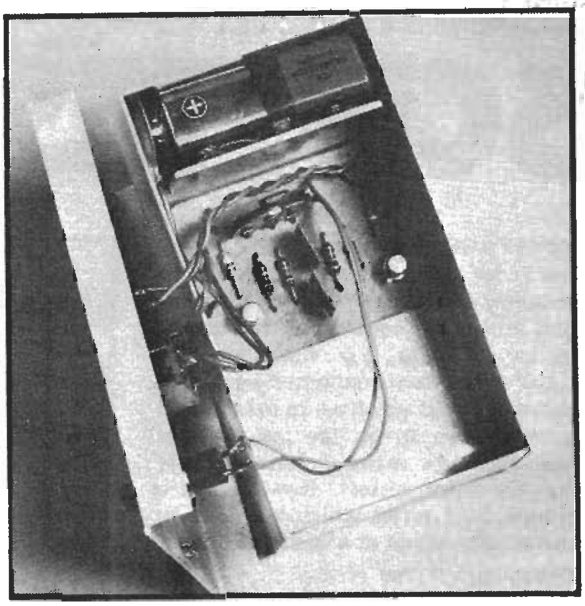


Fig 1: The circuit of our Heads-or-Tails unit.

when the button is pressed. However, electronic components do not have exactly the values they are supposed to have so it is necessary to include potentiometer RV1 to adjust for equal probability. Alternatively it may be useful to maladjust RV1 so that the effect of bias on the results can be assessed.

When either Q1 or Q2 is on, as said before, the associated LED will be on





Internal view of the completed unit.

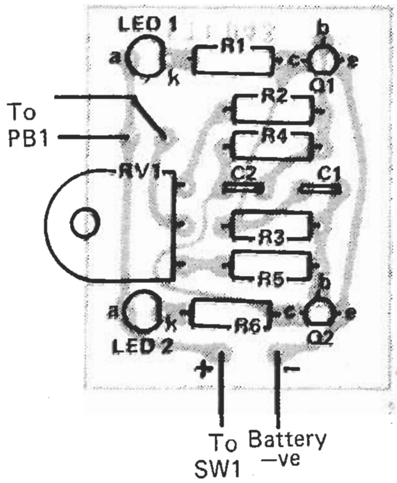


Fig. 3: The component overlay.

Parts List

R1	Resistor	390R ¼w 5%
R2-5	Resistor	47k ¼w 5%
R6	Resistor	390R ¼w 5%
RV1	Potentiometer	47k trim
C1,2	Capacitors	22nF polyester
Q1,2	Transistors	BC108
LED 1,2	Light emitting diodes (large type)	
P.B.1	Press to make	
S.W.1	On/off switch	
Battery	PP3	
Battery clip		
Aluminium box 4 x 2 x 1½in.		

Total cost, inclusive of box and VAT: about £2.00

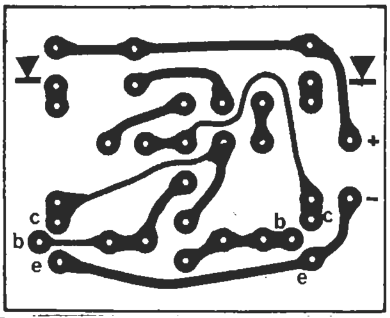


Fig. 2: The PCB layout. Full size 50 x 40mm.

How it works

This circuit may be considered as a multivibrator, when the button is pressed, and as a flip flop when the button is released. If initially we consider the circuit with R2, R5, C1 and C2 deleted we have a standard flip flop. If Q1 is on, it robs current from the base of Q2, thus turning it off. Transistor Q1 will be held on by the current through R6 and R4. However, if Q2 is on, the reverse is the case. Thus only one of the transistors can be on at any time - never both.

The addition of R2, R5 and C1, C2, will not alter the above, providing the push button is not pressed. However if the button is pressed the current through R2 and R5 will try to turn on both transistors.

Take the case where initially Q1 is on and Q2 is off. The voltage on the collector of Q1 will be about 0.5 volts and the voltage on Q2 collector, about seven volts. We therefore have about 6.4 volts across C2 (as the base of Q1 is at about 0.6 volts). When the button is pressed Q2 will turn on and its collector will drop to 0.5 volts.

However a capacitor cannot instantly change its voltage and the base of Q1 will therefore be forced to −5.9 volts which turns off the transistor. Capacitor C2 then discharges via R2 and R4 until the base voltage is again at +0.6 volts when Q1 will turn on again. This however forces the base of Q2 to −5.9 volts (due to C1) thus turning Q2 off. This process continues back and forth until the push button is released. The circuit then stops in the state it was at the instant of releasing the button.

To add bias to the circuit RV1 can be adjusted to change the discharge time of C1 or C2 by up to 50%. In this case the two transistors will not be on for equal times and the results will be biased towards one side.

LEDs are included in the collector circuits of each transistor to indicate which transistor is on. If, for display purposes, a slower-running unit is required the values of C1 and C2 may be increased. If both are 10 microfarad electrolytic capacitors the rate will be about 1.5 seconds. Make sure if electroytics are used that the positive terminal is connected to the collector of the transistor.

and this gives us our 'heads' or 'tails' indication. When the button is pressed, however, the LEDs are switched on and off alternately at a rate of 700Hz. The switching cannot, of course, be seen due to the limited flicker-frequency response of the eye. Both LEDs will therefore appear to be illuminated.

CONSTRUCTION

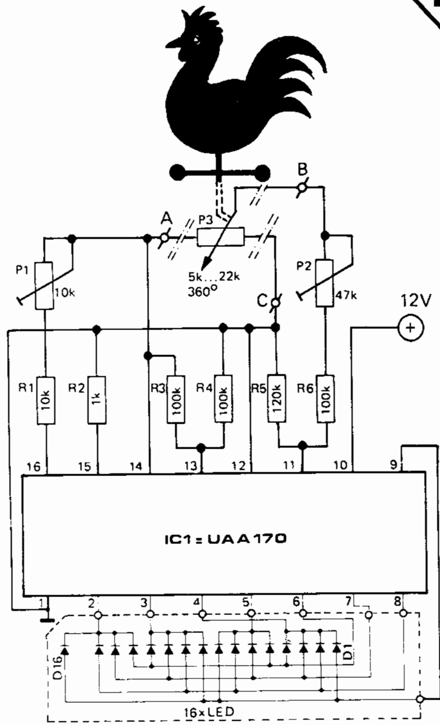
The unit can be assembled onto a small printed-circuit board such as that illustrated.

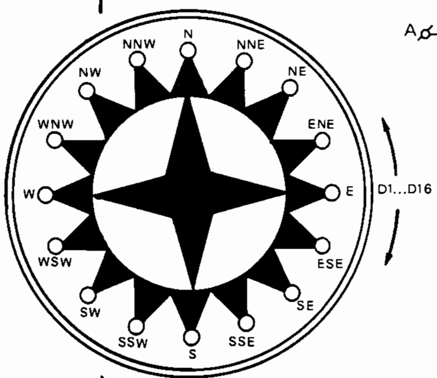
The main points to watch are that the transistors are correctly orientated and that the LEDs are the correct way around.

The unit should be thoroughly checked — a transistor or LED can be destroyed if it is wrongly connected. Double-check the battery connection — a reversed battery can also destroy semiconductors.

48 electronic weathercock

Until recently, finding out which way the wind is blowing has always necessitated putting on one's shoes and stepping outside the door, thereby exposing oneself to the vagaries of the British climate. However with a little technical ingenuity, it is possible nowadays to know the precise direction of the wind without leaving the comfort of one's fireside. The electronic weathercock functions by connecting the vane to a potentiometer which turns with the vane. The voltage at the slider of the potentiometer is then proportional to the angle through which the vane is turned by the wind. The size of this voltage (and hence the direction of the wind) may be displayed in digital form using a UAA 170 and 16 LEDs.
The circuit is designed so that there is a smooth interchange between the LEDs. Potentiometer P1 controls the brightness of the LEDs, whilst P2 is set such that, when the voltage at the slider of P3 (which is connected to the vane) is at a maximum, then D16 lights up. Further details regarding the UAA 170 may be found in Elektor 12, April 1976.
Potentiometer P3 may present a slight problem, in that it must be of a type which can be adjusted through 360°. If such a potentiometer proves difficult to find, then





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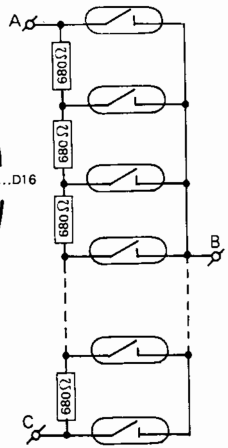


one solution is to use sixteen reed relays, each of which is enabled whenever a magnet connected to the vane passes over the relay. In this case a resistance divider replaces the potentiometer. Readers who are adept at making very small printed circuit boards, may like to replace the carbon track of a conventional potentiometer by a small 16-segment circuit board and connect each segment to the resistance divider.
The supply does not need to be stabilised, since the IC has an internal reference voltage output (pin 14) which is (gratefully) utilised. The maximum current through an LED is approx. 50 mA, thus a suitable supply would be a transformer producing 100 mA with a voltage of 9 or 12 V. The circuit is completed by a bridge rectifier and a 470 μ 25 V electrolytic capacitor.

Reader's Circuits. Indicating that he would welcome pen pals, one of our overseas readers, Ulf Nordquist (Frejas Väg 34, 240 21 Löddeköpinge, Sweden), contributed the circuits shown in Figs. 7 and 8. Ulf has specified standard American devices in his designs, implying that these must be readily available in Europe. In Fig. 7, a 555 timer (*IC1*) is used as the basis for an electronic "coin flipper" featuring red (*LED1*) and green (*LED2*) visual readouts.

With power on, the circuit is operated simply by touching a small metallic plate. In addition to the 555 and the two standard LED's, all that is required for assembly is four half-watt resistors, two small ceramic or plastic film capacitors, a spst switch (*S1*), a 9-to-15 volt battery (*B1*), a small touch plate (about 1 cm on each side), and, of course, wire, solder, a suitable case, and mounting hardware. Component values are not overly critical and, if desired, 1-k resistors can be substituted for the 470-ohm units specified for *R1* and *R2* to reduce battery current drain.

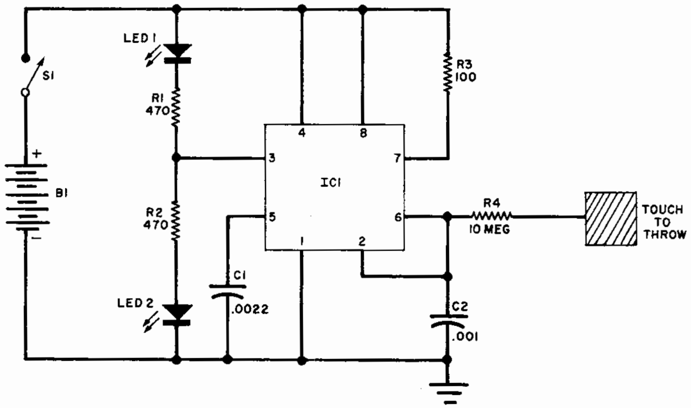


Fig. 7. Electronic coin flipper is operated by touching metallic plate.

Ulf's second circuit, Fig. 8, is an alternate LED flasher featuring a standard 7400 quad NAND gate IC. Here, a 5-volt dc power source is required and a large electrolytic feedback capacitor is employed to achieve a low flashing rate. According to Ulf, the value specified in Fig. 8 establishes a flashing rate of about 1 Hz. This rate may be increased by using a lower value or decreased (made slower) by using a higher value capacitor for *C1*.

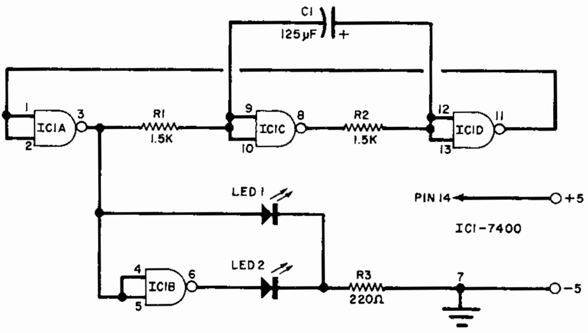
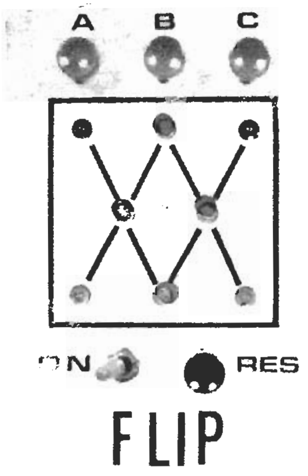


Fig. 8. Flashing rate of LED circuit is determined by value of large capacitor.



BUILD

FLIP

A CMOS GAME COMPUTER

PE TESTED

Do you dare challenge a handful of CMOS chips to a game of logic?

BY JOSEPH A. WEISBECKER

HERE IS a fascinating new electronic game based on digital logic. Called "Flip," it will introduce you to some basic computer concepts, pose a number of interesting mathematical questions, and provide a set of challenging puzzles. The puzzles are easily solved, however, when the proper logic sequence is understood.* Using low-cost CMOS logic and LED readouts, construction of Flip is simplified.

Circuit Operation. There are 8 flip-flops (*A* through *H*) connected as shown in Fig. 1. Eight LED indicators on the front panel show the state of each flip-flop (Fig. 2). A trigger pulse applied to a flip-flop reverses its state. Momentary-contact switches *S1*, *S2*, and *S3* provide trigger pulses for flip-flops *A*, *B*, and *C*. For example, pressing switch *S1* will trigger flip-flop *A* so that, if *LED1* was on, it will go off, and vice versa. The transition from off to on also supplies a pulse to trigger flip-flop *D*. The reversal of *D* then supplies a trigger pulse to *F* or *G*.

The circuits in Fig. 1 actually form a number of 2- and 3-bit interacting counters. For example, flip-flops *C*, *E*, and *G* form a 3-bit binary counter that is triggered each time *S3* is pressed. Figure 3 shows how this counter works. Pressing the reset switch, *S4*, sets the *C*, *E*, and *G* lights as shown in the top row. Now, repeated pressing of *S3* causes the lights to go on and off in the 3-bit binary sequence shown in Fig. 3. The combinations of flip-flops *BEH*, *BDF*, *ADF*, etc. also form 3-bit binary counters.

The circuit in Fig. 1 also contains 8 "memory" cells which remember an 8-bit pattern. This pattern (or state) can be modified by the input switches and is displayed by the LED's. A wired-in "program" controls the change-in-state of the device as a function of the previous state and an input switch. Pressing a single input switch 8 times always returns the device to its initial state, thereby demonstrating its ability to count input switch depressions.

In Fig. 1, *IC5* and *IC6* are quad 2-input NAND gates connected to form three set/reset flip-flops for debounce of the switches. Eight D-type flip-flops are provided by *IC1* through *IC4*, which are triggered by a positive-going edge. Flip-flops *A*, *B*, and *C* are triggered directly by the three debounce flip-flops. Flip-flops *D*, *E*, *F*, *G*, and *H* are each triggered by transitions of other flip-flops. The capacitance-resistance combinations differentiate the outputs of these flip-flops to form positive pulses. For example, *C1-R1* and *C7-R7* differentiate the positive-going not-Q outputs of *A* and *D* to feed an OR gate formed by *D1* and *D7* and trigger flip-flop *F*. Trigger pulses for *D*, *E*, *G*, and *H* are derived in a similar manner.

Integrated circuits *IC7* and *IC8* are hex-inverting buffers used to drive the displays. Resistors *R22* through *R29* were chosen to limit the LED current to about 7 mA. Any LED that provides reasonable brightness for this current can be substituted—possibly reducing the cost. Resistors *R22-R29* can also be reduced in value to increase the brightness of the LED's; but this loads

**Flip is an electronic version of a plastic computer game called "Think-A-Dot" made by Edu-Cards Corp. An article entitled "Mathematical Theory of Think-A-Dot" in the Sept.-Oct. 1967, issue of Mathematics Magazine provided a detailed analysis of the game. The original Think-A-Dot instruction book also provided an extensive discussion of the device, with methods for demonstrating counting, adding, and subtracting of 8-bit binary numbers.*

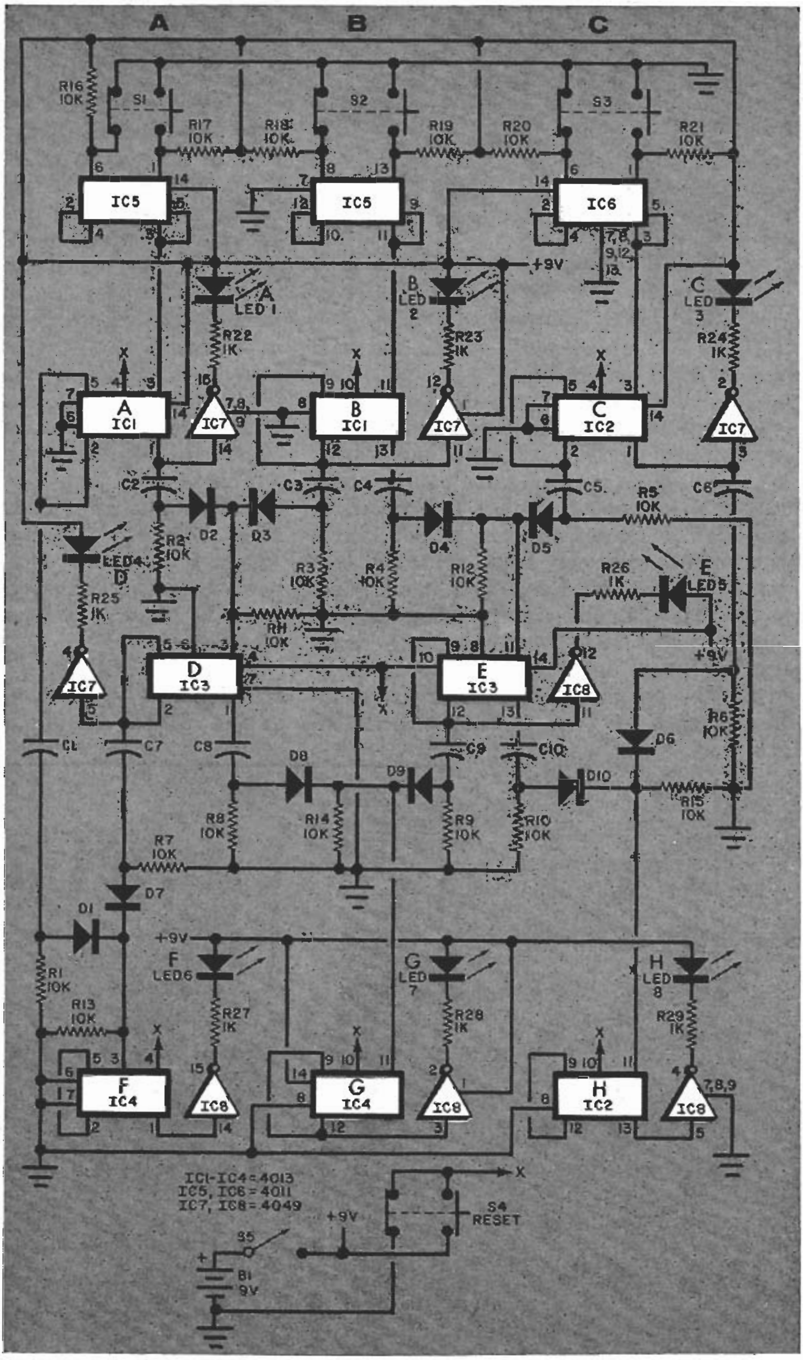


Fig. 1

PARTS LIST

B1—9-volt alkaline/mercury battery
C1-C10—0.033-μF disc capacitor (low voltage)
D1-D10—Silicon diode (1N914 or similar)
IC1-IC4—CD4013 integrated circuit
IC5,IC6—CD4011 integrated circuit
IC7,IC8—CD4049 integrated circuit
LED1-LED8—Any light-emitting diode
R1-R21—10,000-ohm, ¼-watt resistor
R22-R29—1000-ohm, ¼-watt resistor
S1-S4—Spdt switch, momentary closed (Alco MSP-105F or similar)
S5—Spst switch
Misc.—Battery connector, suitable cabinet, "dry-transfer" type, adhesive tape, etc.

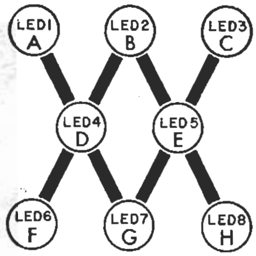


Fig. 2. Arrangement of LED's on the front panel of Flip.

IC7 and *IC8* above rated values and will also decrease battery life.

Construction. The Flip circuit uses CMOS logic circuits since they require low power, have good noise immunity and can be operated with unregulated voltage between 3 and 15 V. However, in using CMOS, some precautions must be kept in mind. All unused gates must have their inputs tied to the plus or minus supply voltage to prevent potential chip burn-out. Care must also be taken in installing the devices. Avoid any possibility of static charges on the inputs. Keep them in the insulation in which they are shipped until ready to solder and use a grounded soldering iron. Low-temperature solder and a low-power iron should be used.

Diodes *D1* through *D10* are not critical; low-current switching types (silicon) were used in the prototype.

The circuit can be assembled on a perf board or on a pc board as shown in Fig. 4. To avoid complexity on the pc board, some short cuts have been taken. Note that *C1* through *C10*, *D1* through *D10*, and *R1* through *R10* are attached together as shown in the insert in Fig. 4 before inserting the loose ends in the pc board. Note that the capacitor end is called out as A, the diode end as B and the resistor end as C on the overall component layout.

There are 19 jumpers that must be made of thin insulated wire and connected between similarly numbered points in Fig. 4 (point 1 to point 1, etc. up to point 16 to point 16). The last three jumpers are from point 17 on *IC1*, *IC2* and *IC3* to point X, the reset circuit.

The eight LED's and the three switches are mounted on the front panel as shown in Fig. 2 and the photo. Also mount the

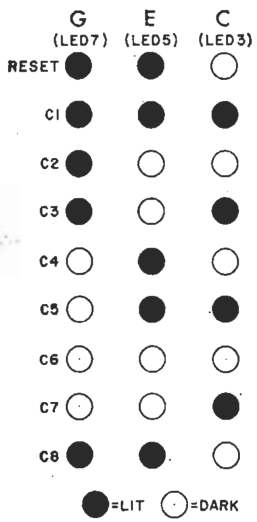
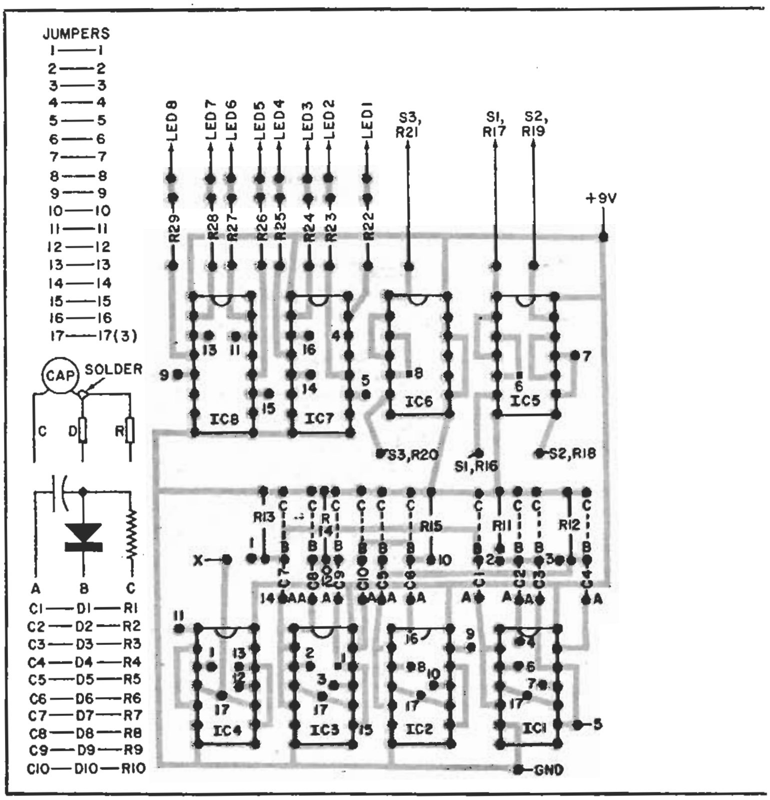


Fig. 3. It takes eight operations of a pushbutton to make the cycle. This shows which LED's come on in sequence.



reset and on/off switches on the front panel. The lines connecting the lights on the front panel can be added in any way desired.

Testing. Turning on the power switch should cause a random pattern to appear on the LED display. Pressing the reset switch should result in the P1 pattern of Fig. 5. If it doesn't, check the reset wiring and voltage connections. After obtaining the P1 pattern, press switches *A*, *B*, and *C* one at a time to verify that all flip-flops are being triggered properly as indicated in Fig. 3. Check signals and wiring for any that fail to operate properly. If the signals to a flip-flop are correct but it still fails to trigger, replace the chip.

Use. Figure 5 shows how Flip is used to solve puzzles. Pressing reset switch *S4* provides the pattern of lights shown at P1. As a sample problem, try to get from pattern P1 to pattern P2 by pressing one or the other of the input switches just 7 times. The other patterns in Fig. 5 can be obtained with the indicated number of switch operations.

An interesting game that can be played is to try to generate specific patterns, with players taking turns pressing just one switch at a time. Starting with the reset switch operated to set the original pattern, the goal is to obtain a pattern consisting of a triangle of lights (either *ACDEG* or *BDEFH*). It doesn't matter if additional lights are on as long as one of the two winning triangles appears. Of course, other patterns, easier or harder, can be chosen as the winning pattern. Since it is possible to predict what pattern is going to appear next, considerable skill can be developed.

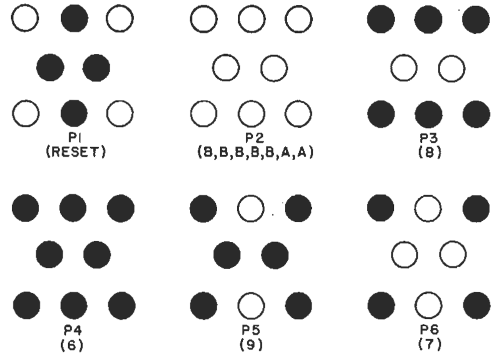


Fig. 5. Pattern after reset is P1. To get P2, press switches as shown. Other patterns take indicated number of switch operations.

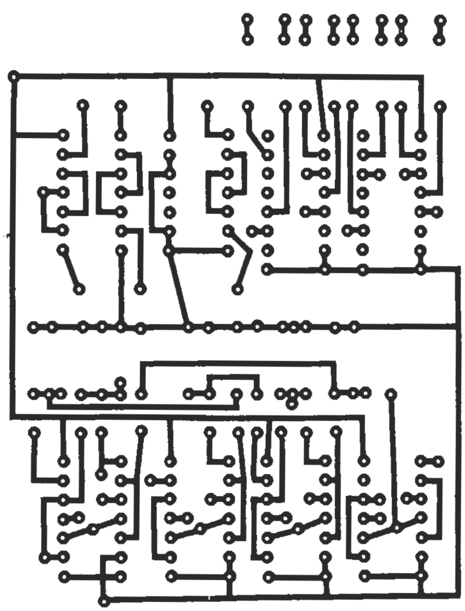
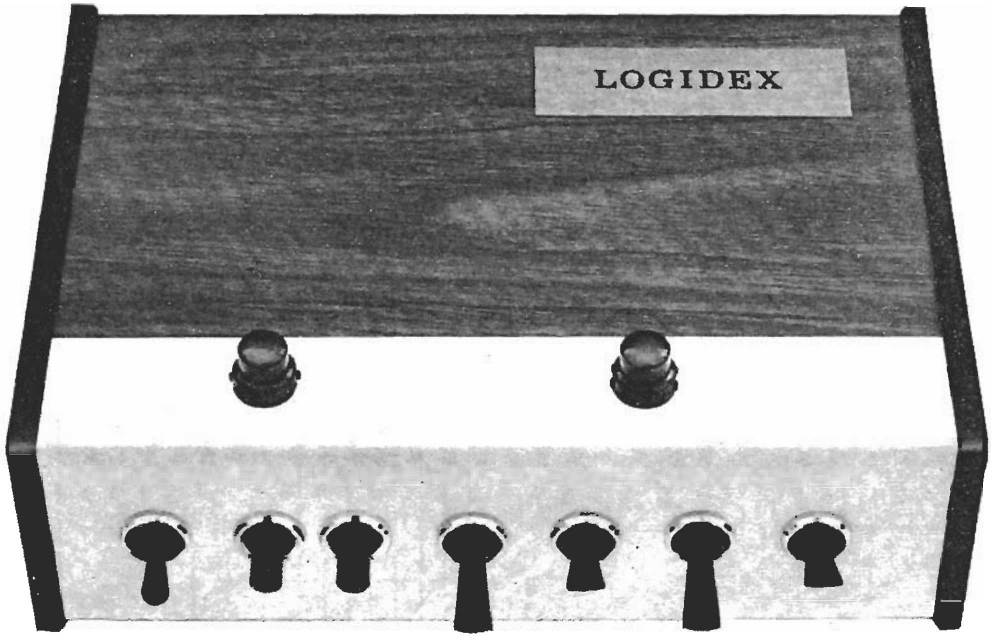


Fig. 4. Either a perf board or printed circuit board can be used for the circuit. Note how the C-D-R assembly is made. Be sure to install the jumpers.

Flip provides some insight into why bugs occur in large computers after months or even years of use. These machines have thousands of possible states, many of which remain untested until someone happens to write a program that causes one of these states to occur. Flip, with only 8 flip-flops, has relatively few possible states, but it is still nontrivial in a mathematical sense. For example, how many of the potential 256 states (or patterns) can be obtained starting from the reset state? Can you develop an algorithm (set of rules) for finding the shortest sequence of switch depressions to transform one pattern to another?

Here is another interesting property of Flip. If the sum of the lights that are on in the top and bottom rows is even, then pressing *A*, *B*, and *C* any number of times will leave this sum even. In other words, the parity of these 6 bits (lights) can't be changed by the input switches. This concept of parity is used for error checking in computers. For example, a switch input can only change the parity of the 6 bits of the top and bottom rows if a circuit malfunction occurs. This condition could easily be detected and used to turn on an error light. ◈



LOGIDEX

PE TESTED

AN ELECTRONIC GAME FOR ALL SEASONS

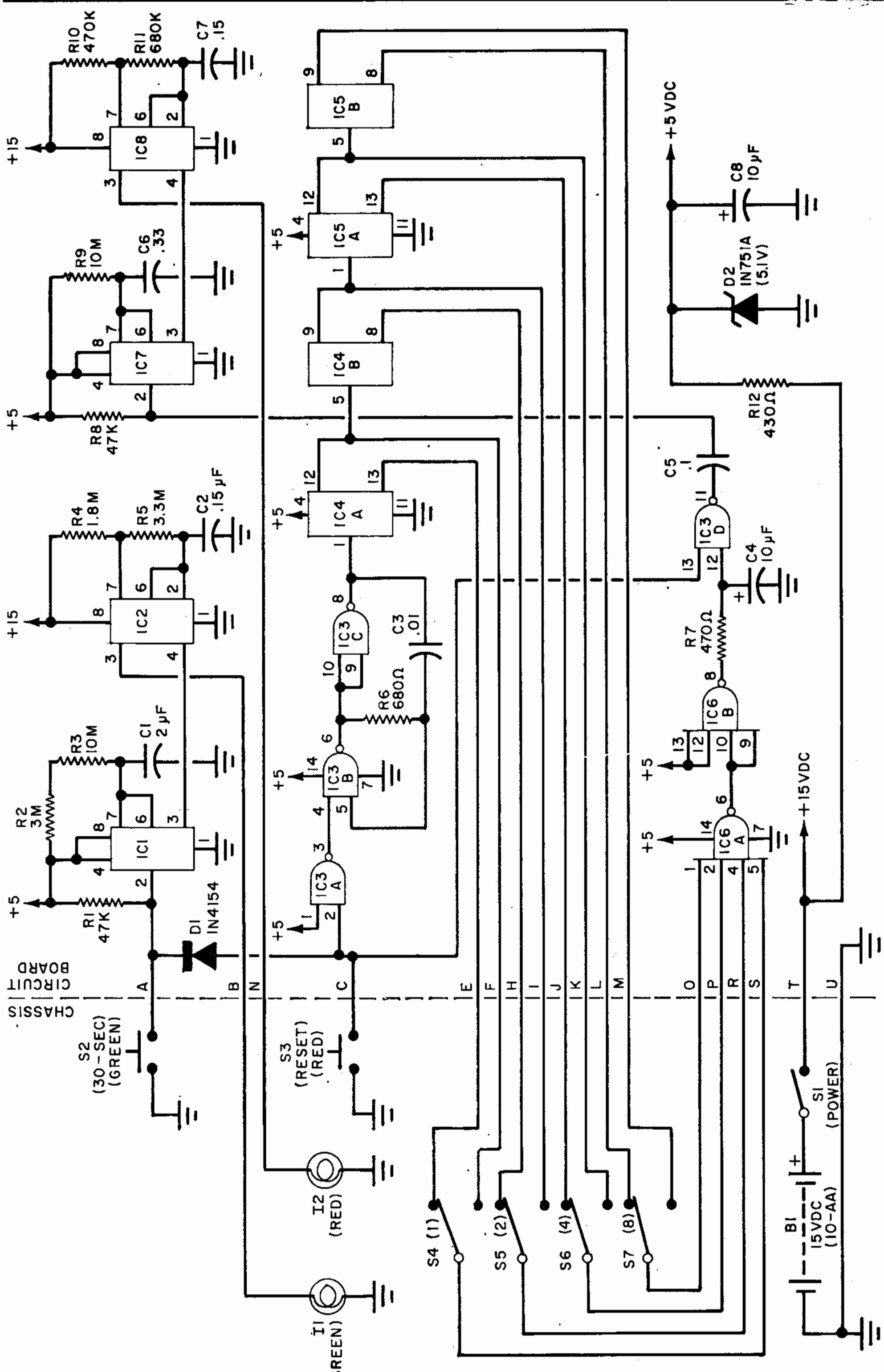
Flashing light game for all ages uses digital logic

BY HOWARD L. NURSE

CHILDREN are fascinated by switches and flashing lights, while adults are attracted to games of chance. Here is an electronic game you can build which bridges the gap and can be enjoyed by persons of all ages.

We call the game "Logidex," a combination of logic and dexterity, both of which are required to win the game.

The table describes some ways in which the Logidex can be used. The games are based on a player's ability to logically decode an unknown four-bit binary number as rapidly as possible with an array of four switches. Each time the player succeeds in finding the number with a correct combination of "up" and "down" game switches, a red light flashes for four seconds. After four seconds, the player presses the red switch to generate a new random number, and plays again. This sequence, which was initially started by pressing the green switch, continues for thirty seconds, as timed by a green flashing light.


R1 47K
R2 3M
R3 10M
C1 2µF
IC1
D1 1N4154
R4 1.8M
R5 3.3M
C2 .15µF
IC2
R8 47K
R9 10M
C6 .33
IC7
R10 470K
R11 680K
C7 .15
IC8
IC3 A
IC3 B
IC3 C
R6 680Ω
C3 .01
IC4 A
IC4 B
IC5 A
IC5 B
+5VDC
C8 10µF
D2 1N751A (5.1V)
R12 430Ω
C5 .1
IC3 D
C4 10µF
R7 470Ω
IC6 B
IC6 A
+15VDC
CIRCUIT BOARD
CHASSIS
S2 (30-SEC) (GREEN)
S3 (RESET) (RED)
I2 (RED)
I1 (GREEN)
S4 (1)
S5 (2)
S6 (4)
S7 (8)
B1 15VDC (10-AA)
S1 (POWER)

PARTS LIST

B1—AA cell (10)
C1—2-μF, 200-volt capacitor (Sprague "Orange Drop" or similar)
C2,C7—0.15-μF, 100-volt capacitor (Sprague "Orange Drop" or similar)
C3—0.01-μF disc capacitor
C4,C8—10-μF, 30-volt electrolytic capacitor
C5—0.1-μF disc capacitor
C6—0.33-μF, 100-volt capacitor (Sprague "Orange Drop" or similar)
D1—Diode (1N4154 or similar)
D2—5.1-volt, 1N751A zener diode
I1,I2—12-volt, 60-mA lamp (red and green)
IC1,IC2,IC7,IC8—NE555V integrated circuit
IC3—SN7400/SN74L00N (see text)
IC4,IC5—SN7473/SN74L73N (see text)
IC6—SN7420/SN74L20N (see text)
R1,R8—47,000-ohm, ¼-watt, 10% resistor
R2—3-megohm, ¼-watt, 10% resistor
R3,R9—10 megohm, ¼-watt, 10% resistor
R4—1.8 megohm, ¼-watt, 10% resistor
R5—3.3 megohm, ¼-watt, 10% resistor
R6—680-ohm, ¼-watt, 10% resistor
R7—470-ohm, ¼-watt, 10% resistor
R10—470,000-ohm, ¼-watt, 10% resistor
R11—680,000-ohm, ¼-watt, 10% resistor
R12—430-ohm, ¼-watt, 10% resistor
S1—Spst switch
S2,S3—Spst, normally open pushbutton switch (red and green)
S4-S7—Spdt switches (bathandle type)
Misc.—Battery holders, cabinet (Ten-Tec JW-8), mounting hardware, etc.

Fig. 1. The game consists of four portions: a 30-second timer and flasher, a clock, a ripple counter, and a 4-second timer-flasher.

How It Works. The schematic for Logidex is shown in Fig. 1. The circuit can be divided into functional blocks as follows: a thirty-second timer and flasher (*IC1,IC2*); clock oscillator (*IC3B* and *C*); counter (*IC4,IC5*); qualification logic (*IC6, IC3D*); and four-second timer and flasher (*IC7, IC8*). In addition there are the power supply and the controls.

Pressing the green switch (*S2*) causes the

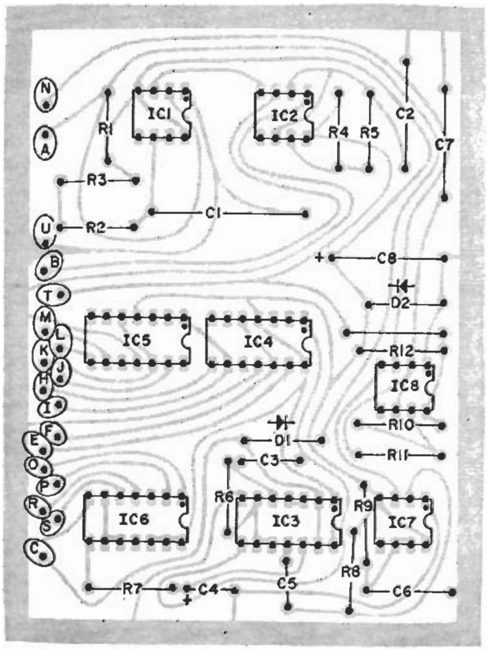
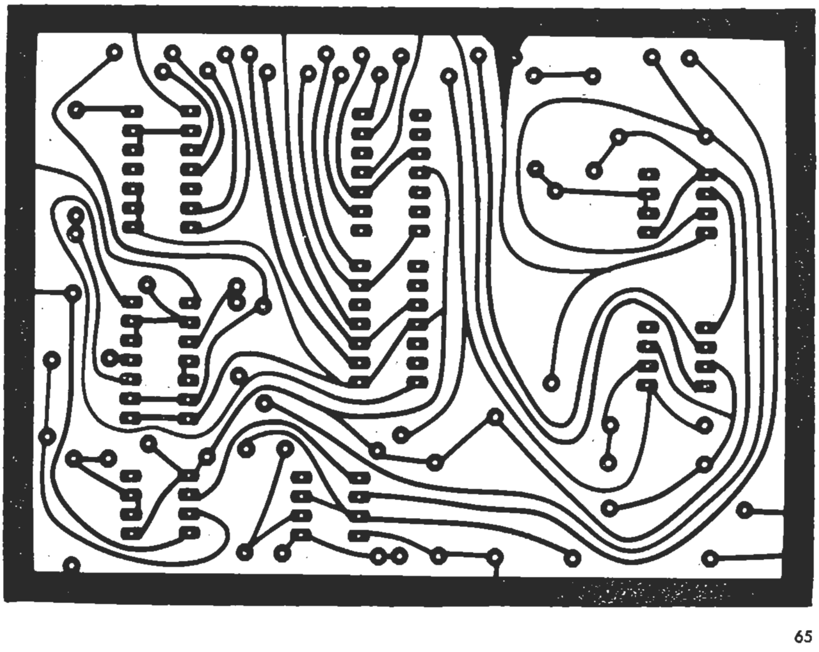
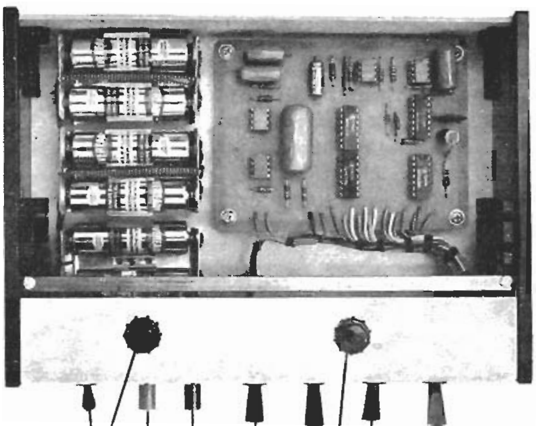


Fig. 2. Actual-size foil pattern and component installation. Observe all polarities.





Use large bathandle-type switches for easy operation. Switch S1 and lamp I1 are green, while switch S2 and lamp I2 are red colored.

GAMES TO PLAY

Game	Rules
Logi-Peg	1. Use a cribbage board with pegs. Assign one peg to each player.
	2. Each player advances his peg one hole per win during his thirty-second play period.
	3. Play last "round" after one player reaches end.
	4. Player to advance farthest after all players have had an equal number of turns wins.
Logi-Sum	1. Assign a number (any number, including Roman numerals) to each switch.
	2. Player must sum the "up" switches after each win.
	3. First player to exceed a pre-determined total (such as 100) wins.
Logi-Lette	1. Draw a circle and divide it into 16 sections, numbering the sections from 0 to 15.
	2. Assign the game switches the numbers 1, 2, 4, and 8.
	3. Each player chooses one numbered section of the circle.
	4. One player plays Logidex and sums the "up" switches.
	5. The player whose chosen section number corresponds to the score wins.

thirty-second timer to start and also enables the clock to oscillate for an unknown number of cycles. The clock oscillates at approximately 50 kHz, so that many cycles pass while the switch is pressed. The red switch (*S3*) also enables the oscillator, but it is isolated from the thirty-second timer by diode *D1*.

The clock output (from *IC3C*) is used to trigger a four-bit ripple counter (*IC4,IC5*). Both the normal and inverted outputs from each stage of the counter are wired to switches so that one throw of each switch will always have a logic 1 connected to it.

When the switches have been toggled to the correct positions, all four inputs to *IC6A* are at a logic 1. The output from *IC6B* goes high under this condition, passes through a low-pass filter (*R7,C4*) to remove noise transients, and triggers the four-second timer and flasher. Integrated circuit *IC3D* allows the circuit to function only during normal play and inhibits the output of the qualification logic when the clock is causing the counter to operate.

The power supply consists of ten AA batteries with a zener regulator for the IC supplies.

Construction. The circuit can be constructed on a printed circuit board such as that shown in Fig. 2. The assembly of the prototype is shown in the photos. Note that the lamp connections from points B and N on the circuit board are routed separately from the main harness. This routing is necessary to isolate the fifteen-volt flash signals from the sensitive flip-flop inputs and outputs. Be sure to unscrew the lamps while soldering the sockets to prevent costly damage to the filaments.

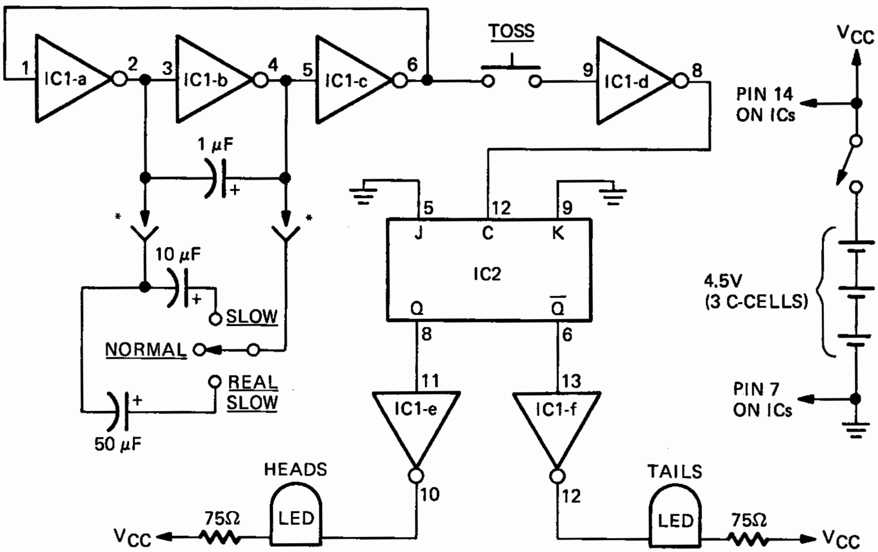
When selecting components, keep in mind that high impedances are present in the timing circuits, so low-leakage capacitors are necessary for *C1* and *C6*. Sprague "Orange Drop" capacitors were used for *C1*, *C2*, *C6*, and *C7* to stabilize the flash rates and timing.

While standard TTL logic gates (such as SN7400) can be used, low-power logic (such as SN74L00) is recommended to conserve power and prolong battery life. When using an SN7400 instead of an SN74L00 for *IC3*, it is necessary to lower the values of *R6* and *R7* to 220 ohms and R12 to 120 ohms, 2W. Logic speed, which is reduced when using low-power gates, is not a critical consideration in this application. ◈

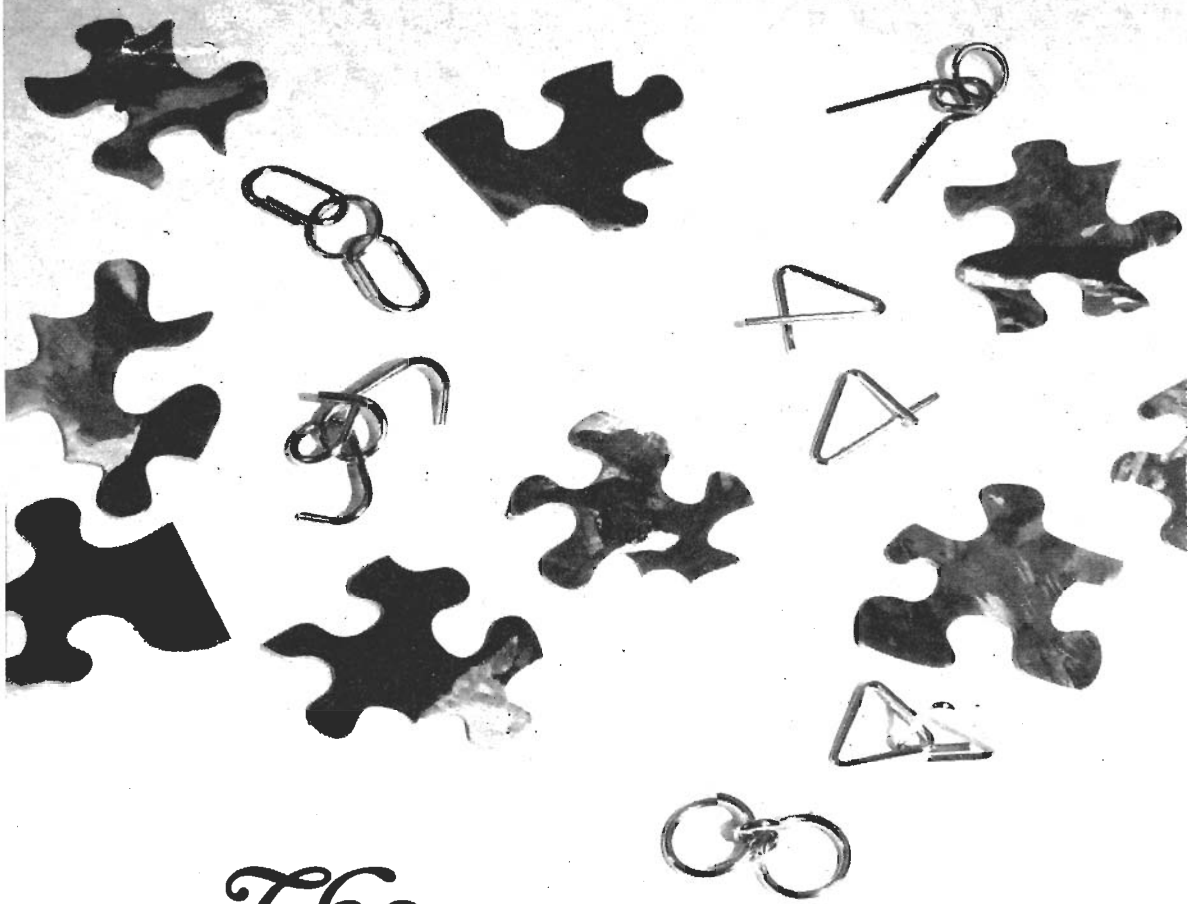
circuits

ELECTRONIC COIN TOSS

As a correspondence-school student I find that you must experiment with actual devices to really develop a knowledge of any segment of electronics. Here is a circuit I developed as an introduction to two high-technology devices—TTL IC's and LED's. It is an IC/LED version of the Coin Tosser (See "Electronic Coin Tossing", *Popular Electronics,* January, 1956). It is so simple that the schematic shown should suffice. Parts are readily available.—*John Goegl, WA2LJK*



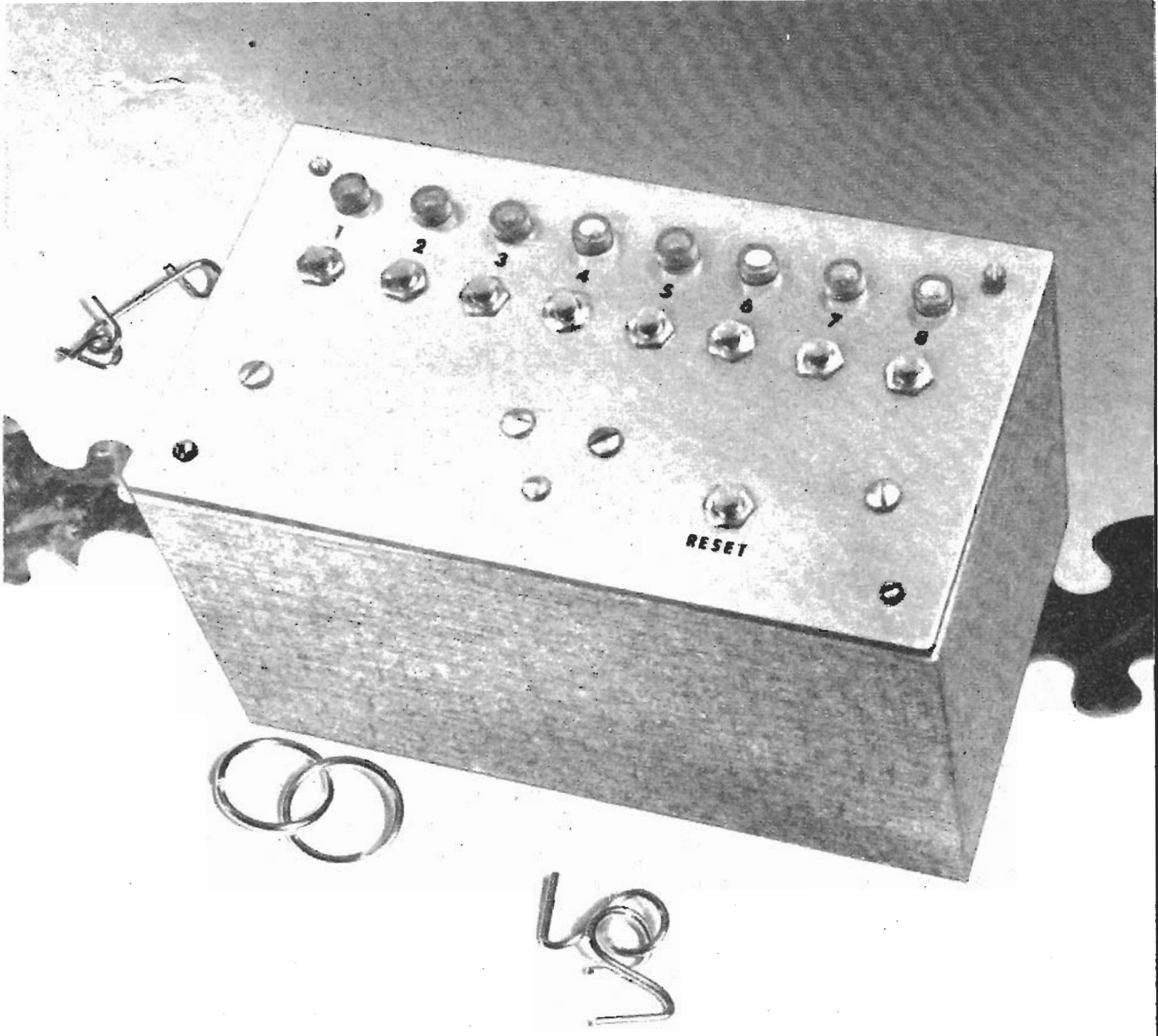
*OPTIONAL
IC1 TTL **7405** HEX INVERTER
IC2 TTL **7470** J-K FLIP-FLOP



The PRINCEPS PUZZLE

Assemble the first all-electronic puzzle

BY JAMES W. CUCCIA



PUZZLES—whether they are word games, jigsaws, entwined nails, or interlocked pieces of wood—are the joy (or bane) of many people's existences. Whatever the overall reaction, however, nearly everyone is fascinated by a real "toughie"—providing he is assured the solution is possible and the whole thing is not a hoax.

Presented here is an ancient puzzling principle in a new guise—the electronic "Princeps Puzzle." The solution to Princeps Puzzle is based on clear-cut rules of logic (as used in everyday computers) and, assuming you get your unit properly assembled and wired, it is definitely possible—though not quickly obtained through some trick of black magic.

There are eight lights and eight pushbuttons on the puzzle. There

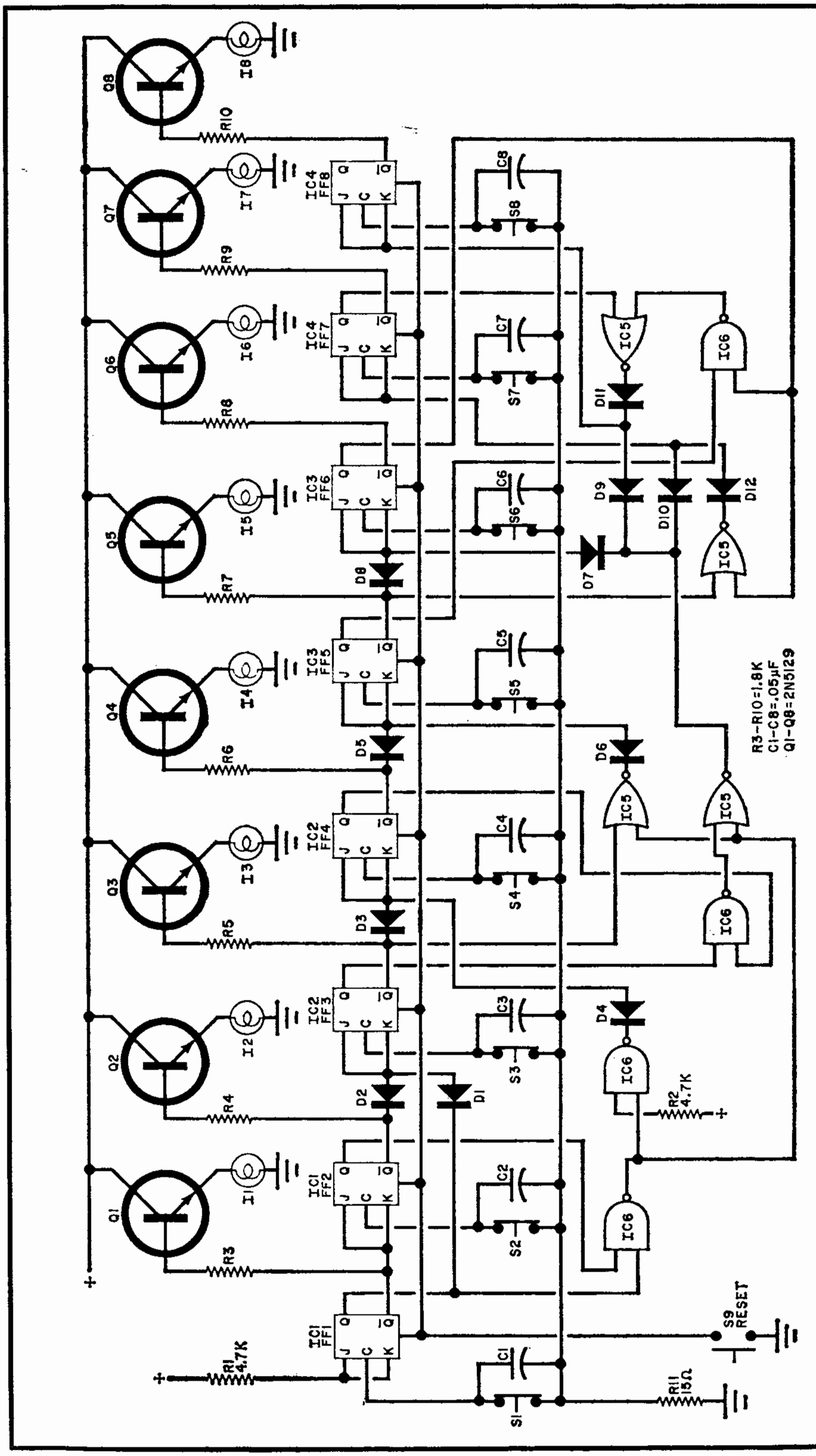
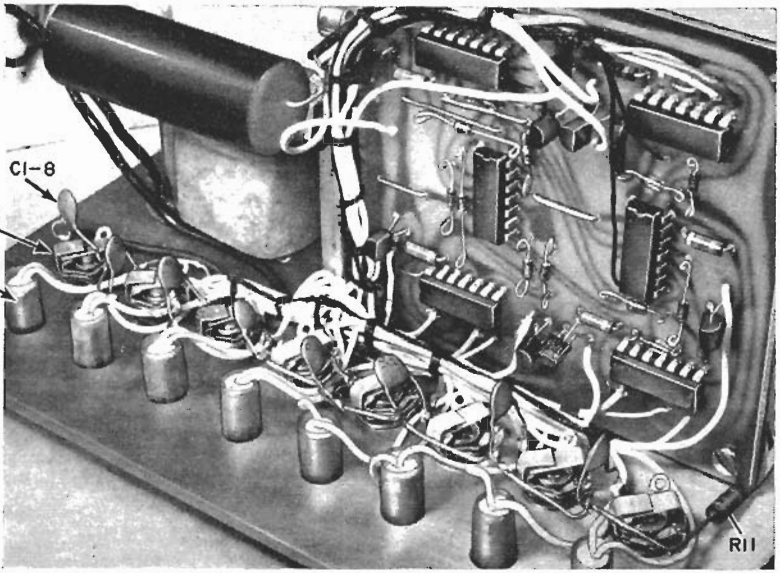


Fig. 1. Note that there is no actual trigger pulse applied to the flip-flops. Merely opening the associated pushbutton is enough to toggle the stage. The capacitor on the switch removes contact bounce.



Construction is left to the builder. Here, the lamps, switches and capacitors are grouped in lines on the front panel. The PC board is mounted on a pair of brackets.

is also a reset button which, when pressed, turns on all the lights at any time. The point of the puzzle then is to get them all turned off again by pressing the appropriate numbered buttons. You can figure out the solution to the Princeps Puzzle from the logic diagram shown in Fig. 1; and we'll give you a hint—it takes 170 pushes of one button or another in the proper sequence to get all the lights off. Once you get the system down pat, you'll be able to turn off all the lights in a minute or two—after watching your friends push and puzzle and puzzle and push for hours.

The detailed procedure for all 170 steps is too long to print here—besides we don't want to spoil your fun—but we'll send you a copy if you send 20¢ to cover handling and mailing to Editorial Dept., POPULAR ELECTRONICS, One Park Ave., New York, NY 10016.

PARTS LIST

C1-C8—0.05-μF disc capacitor
D1-D13—Small-signal silicon diode
I1-I8—6.3-volt, 50-mA pilot light
IC1-IC4—Dual JK flip-flop (Motorola MC-7473P)
IC5—Quad 2-input NOR gate (Motorola MC-7402)
IC6—Quad 2-input NAND gate (Motorola MC7400)
Q1-Q8—2N5129 transistor
R1,R2—4700-ohm, ¼-watt resistor
R3-R10—1800-ohm, ¼-watt resistor
R11—15-ohm, ½-watt resistor
S1-S9—Spst pushbutton switch (Switchcraft 103 or similar)
Misc.—Suitable chassis, plastic lens for lamp (8), line cord, grommet, mounting hardware, etc.
Note: The following are available from Southwest Technical Products, 219 W. Rhapsody, San Antonio, TX 78216: etched and drilled PC board at $2.90, postpaid; complete kit of parts including board, chassis, and power supply at $29.95, plus postage and insurance for 3 lb.

Construction. The electronic portion of Princeps Puzzle is assembled on a printed circuit board as shown in Fig. 2. Be sure to get the proper orientation on the IC's and the correct polarities on the diodes. Use a low-wattage soldering iron and fine solder to avoid damaging the semiconductors with heat. The eight lights and their associated pushbuttons and capacitors are mounted on the front panel along with the reset button and *R11*. Once these are installed, the circuit board can be attached to the front panel as shown in the photographs.

The wiring between the switches, lamps, and board is not critical but it should be color coded to avoid confusion. A line-operated power supply, delivering approximately 5 volts is shown in Fig. 3. This supply may be assembled within the chassis using terminal strips to hold the components.

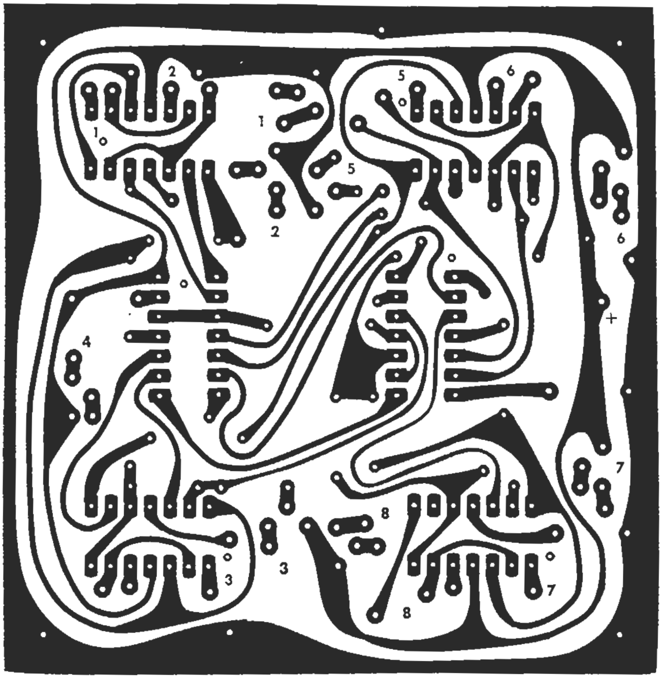
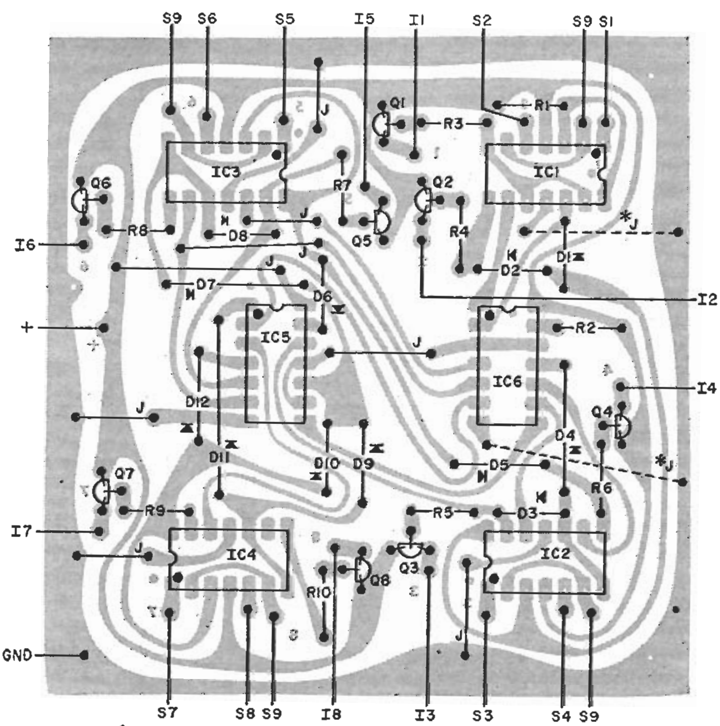
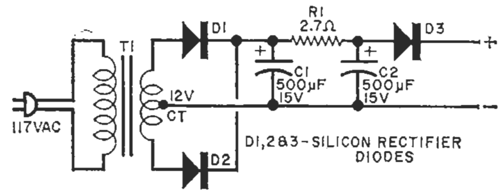


Fig. 2. Actual size foil pattern (left) and component installation (below) for the puzzle. Note that two insulated jumpers are shown and can go on foil side of the board.





PARTS LIST

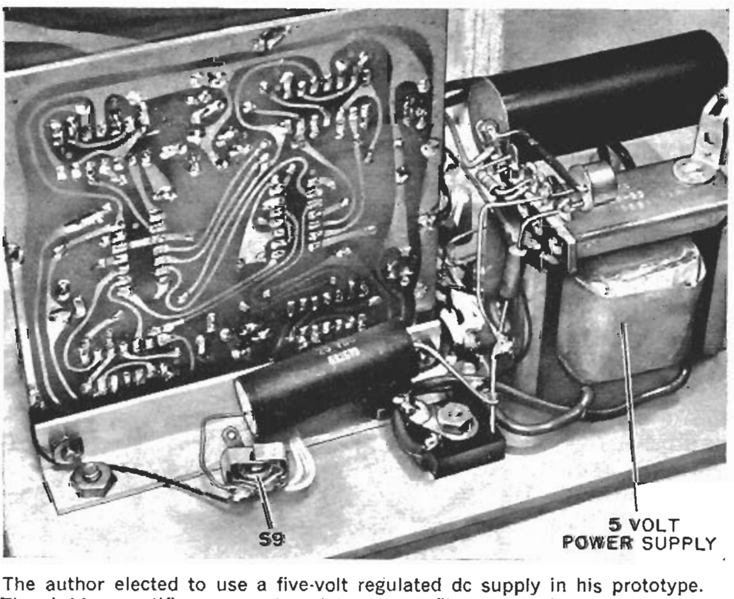
C1,C2—500-μF, 20-volt electrolytic capacitor
D1-D3—50-PIV, 1A silicon diode
R1—2.7-ohm, 1-watt resistor
T1—Transformer; secondary 12 VCT, 1A

Fig. 3. Typical power supply for use with the puzzle. Any other type of five-volt supply may be substituted.

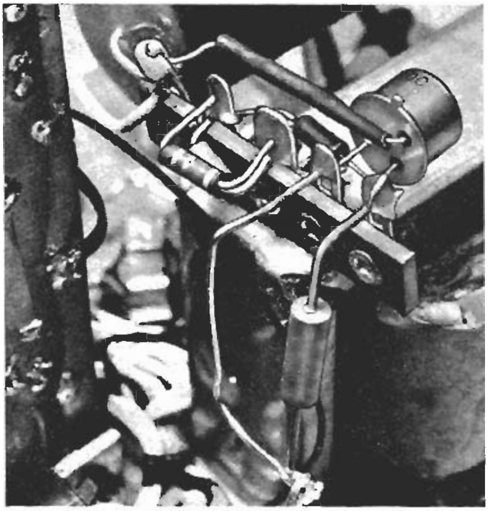
Theory of Circuit Design. The circuit uses four dual JK master-slave flip-flops, a quad two-input NAND gate, and a quad two-input positive NOR gate. The lamps are driven by emitter followers which are connected to the $\bar{Q}$ output of the flip-flops. In Fig. 1, the flip-flops are numbered to correspond to the lamps that they control.

The JK inputs to *FF1* are held at a high level at all times so that any pulse on the C input changes the Q output and turns *I1* on or off. The $\bar{Q}$ output of *FF1* also controls the JK inputs to *FF2*. Thus *FF2* can be changed by a pulse on C only if the $\bar{Q}$ output of *FF1* is high—meaning *I1* is on. The Q output of *FF1* is coupled to *FF3* through diode *D1* and to one input of the NAND gate which is one of the controls for *FF4* through *FF8*. Thus *FF3* through *FF8* are operative when *I1* is off and the other control levels are correct. The $\bar{Q}$ output of *FF2* is coupled to *FF3* through *D2* so that *FF3* can function only when *I1* is off and *I2* is on. The Q output of *FF2* is coupled to *FF4* through *FF8* through a NAND gate so that they can operate only when *FF2* is off and other conditions are met.

The $\bar{Q}$ output of *FF3* is coupled through *D3* to *FF4* so that the latter can only operate when *I3* is lit. The $\bar{Q}$ output of *FF3* is also coupled to a NOR gate and its Q output to a NAND gate. These gates control *FF5* through *FF8* so that they cannot operate unless *I3* is off. The $\bar{Q}$ output of *FF4* is coupled to *FF5* through *D5* so that *FF5* can operate only when *I4* is on. The Q output of *FF4* is connected to one input of a NAND gate coupled



The author elected to use a five-volt regulated dc supply in his prototype. The bridge rectifier, pass transistor, and filters can be seen above.



This view shows the value in using a terminal strip to mount off-board electronic components, in this case the regulated power supply. Such an approach can be used in any type of supply, or in any other project that requires outboard component mounting.

to *FF6*, *FF7*, and *FF8* so that they can operate only when *I4* is off and other conditions are met.

The $\overline{Q}$ output of *FF5* is connected through *D8* to *FF6* so that *FF6* can operate only when *I5* is on. The $\overline{Q}$ output of *FF5* is also connected to a NOR gate while its Q output is connected to a NAND gate to control *FF7* and *FF8* so that they can operate only when *I5* is off and other conditions are met. The Q output of *FF6* is used only as a lamp drive but its Q output is connected to a NOR gate to control *FF7* and to a NAND gate to control *FF8* so that *FF7* can operate only when *I6* is on and *FF8* can operate only when *I6* is off.

The $\overline{Q}$ output of *FF7* is used only to drive *I7* and its Q output is connected to a NOR gate to control *FF8*. Thus *FF8* can operate only if *I7* is on. The Q output of *FF8* is used as a lamp drive only.

The clock input to each flip-flop requires that the input be held low, increased momentarily, and then returned to low. This condition is met by the normally closed pushbutton switches *S1* through *S8*. A capacitor across each switch integrates the pulse and eliminates contact bounce.

The overall logic circuit then controls the lamps so that *I1* can be turned on or off at any time and to change the condition of any other lamp, the lamp immediately preceding the one to be changed must be on and all other lamps preceding that one must be off. This is the format that must be followed in solving the puzzle.

There are two modifications that can be tried. To make it easier, only the first six lamps and their associated circuits can be used —eliminating *I7* and *I8* and associated circuits. To make things more difficult, interchange the pushbuttons so that they don't line up with the lights—but be sure you know what's what or you may wind up on the puzzled side yourself. —30—

OUT OF TUNE

"Princeps Puzzle," May 1971. Diode *D11* in Fig. 1 is shown installed incorrectly. The cathode and anode leads of the diode should be interchanged. The diode is shown installed with the correct polarity in the components layout diagram in Fig. 2.