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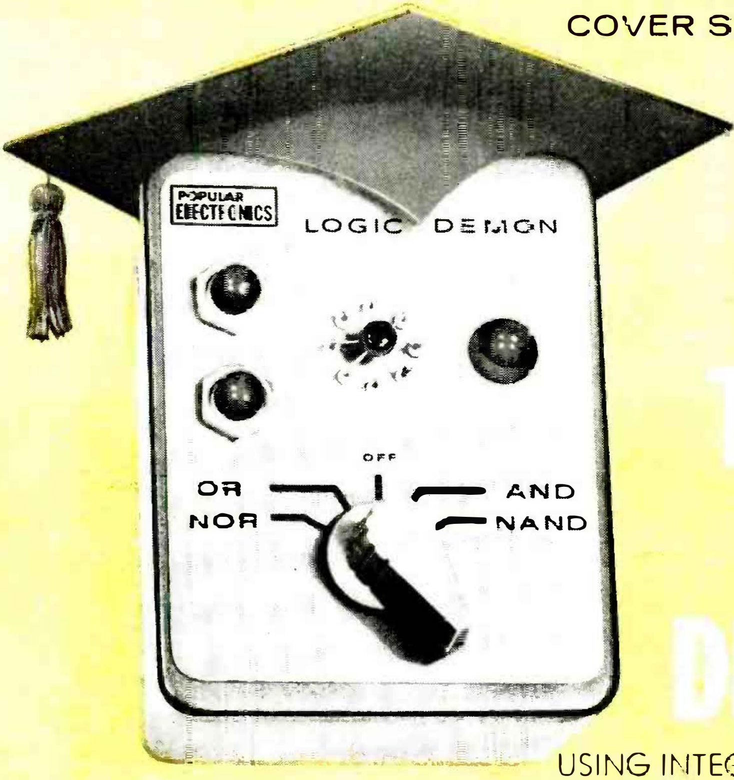



## SCIENCE FAIR PROJECT

# THE LOGIC DEMON

USING INTEGRATED CIRCUITS (IC'S), THE **DEMON**STRATOR DUPLICATES THE LOGIC FUNCTIONS OF GIANT ELECTRONIC COMPUTERS

**By DON LANCASTER**

EVER wondered how is it that electronic computers are able to exhibit such a distinctively human characteristic as making logical decisions? Ask the "Logic Demon" and it will tell you that, very simply, the answer lies in the truth of logic—computer logic.

And what IS logic? It is the process of determining, by deductive reasoning, the means of obtaining a desired result from a given set of conditions. Consider the following paradoxical dialogue involving *formal* logic which dates back to Aristotle:

*Socrates:* "What Plato is about to say is false."

*Plato:* "Socrates has just spoken the truth."

Now, if Socrates spoke the *truth,* then Plato's statement must be *false*. But if Plato's statement is *false,* then Socrates *did not* speak the truth and, hence, what Plato said must have been *true*. If Plato spoke the *truth*, then Socrates also spoke the *truth,* and hence what Plato said is *false*. Needless to say, this circular process could go on and on. But can this formal logic be reasoned out mathematically?

The Logic Demon, utilizing the latest in resistor-transistor logic (RTL) circuitry, can serve as a demonstrator/trainer in computer logic—the same logic used by the giant sophisticated digital computers. And you can build the Logic Demon for under $10 to show off at your next Science Fair.

**Computer Logic.** Computer logic, also known as Boolean Algebra, translates Aristotle's *formal* logic to a *mathematical* logic which can be used for reasoning out problems. Developed by Augustos De Moran and George Boole over 100 years ago, Boolean Algebra (computer logic) was crystalized in 1938 by Claude E. Shannon who, while studying for his Master of Science degree at M. I. T., applied it to the solution of switching problems.

As an example of Shannon's application of computer logic to solve practical problems, consider the simple series circuit shown in Fig. 1. Two switches (*A* and *B*) are in series with lamp *I* and a battery. If you ask which switch must be closed in order for current to flow and light the lamp, the answer would be that *both* switches—*A* AND *B*—must be closed. Thus, the circuit is called an AND *gate*. A gating circuit is one that operates as a switch to apply or eliminate a signal.

Following a logical procedure, a table can be made listing all possible switch combinations to prove that switches *A* and *B* must be closed at the same time or current will not flow. Thus,

| Switch "A" Closed | Switch "B" Closed | Lamp "I" Lights |
|---|---|---|
| No | No | No |
| No | Yes | No |
| Yes | No | No |
| Yes | Yes | Yes |

As shown in the table, a "yes" appears in the lamp column only when a "yes" appears in both switch columns. The table can be simplified by substituting a "0" (zero) for a "no" and a "1" for a "yes." This allows us to establish a convention to symbolize that a statement or condition is *false* when a 0 is represented, while a 1 can be used to denote that a statement or condition is *true*. The simplified table is as follows:

| Switch "A" Closed | Switch "B" Closed | Lamp "I" Lights |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

In computer logic (also called symbolic logic), the preceding table is known as a *truth table* for the logical AND for it represents the simple true statement that the lamp lights only when both *A* AND *B* are closed at the same time.

If the same switches are rearranged and connected in parallel as shown in Fig. 2, the following table can be pre-

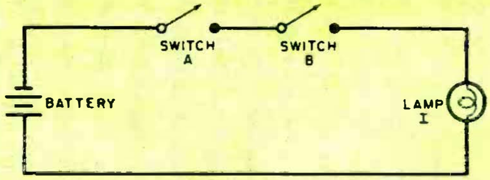



Fig. 1. Switches A and B in series with a battery and lamp can represent the logical AND circuit.

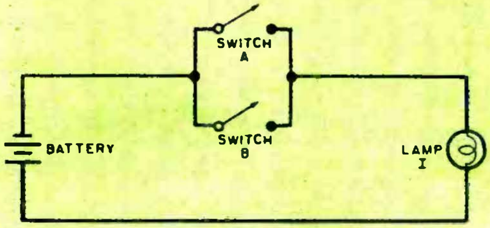
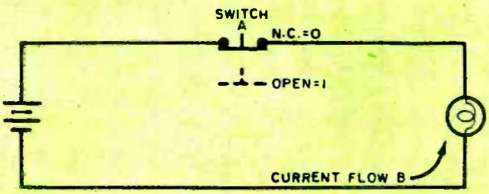



Fig. 2. In the logical OR circuit, current flows if either switch A or switch B, or both, are closed.




| SWITCH A | CURRENT B |
|---|---|
| O | I |
| I | O |

Fig. 3. In this circuit, the lamp lights when A is NOT pushed; the circuit is called a NOT gate.

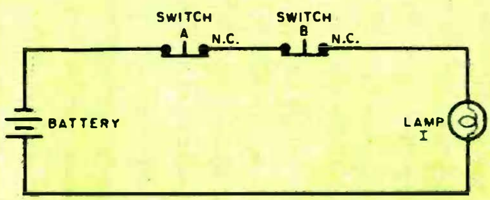



Fig. 4. A NOR gate is represented by adding one or more switches to the NOT gate described above.

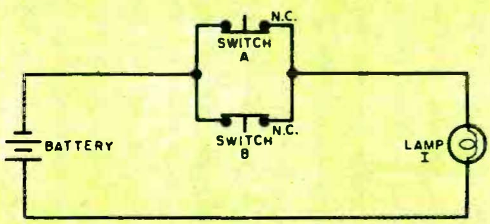



Fig. 5. The NAND function can be depicted by normally closed parallel-connected switches A and B.

pared to show for what switch combination the lamp will light:

| Switch "A" Closed | Switch "B" Closed | Lamp "I" Lights |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

The lamp lights when either one or both of the switches are closed. Thus, logically, *I* is 1 (true) whenever *A* OR *B* (OR *A* and *B*) is true (closed), and the circuit is called a logical OR gate.

Consider the circuit of Fig. 3. Unactuated, normally closed (NC) switch *A* represents a 0, but when pressed, the switch represents a 1. The corresponding truth table asserts that *B* (current flow) is 1 whenever *A* is 0, and that *B* is 0 whenever *A* is 1. In other words, the lamp lights (is 0) when the switch is NOT pushed, and is extinguished when the switch is pushed (1). The circuit is characterized by a single switch, and is called a NOT gate (inverter).

By adding one or more switches to the NOT circuit, we come up with what is called a NOR gate (Fig. 4). A truth table for this circuit would state simply that *C* (current through the lamp) is true only if both *A* and *B* are false, and that *C* is false if either *A* or *B* is true. Since these conditions represent the opposite (negative) of the OR—NOT OR—it is called simply a NOR gate.

The opposite (NOT) of the AND gate can be represented by the circuit of Fig. 5. The NOT AND, or briefly, NAND, function can be depicted by the normally closed parallel-connected switches (*A* and *B*). The lamp lights if *either* or *both* switches are left in their "0" position. But it will be extinguished if both switches are "1" (pressed) at once.

**Applying Computer Logic.** A computer is capable of carrying out a long string of YES-NO decisions without having to repeatedly ask for more information as the operation progresses.

Depending on the complexity of the problem to be solved, thousands upon thousands of such decisions, may be needed for mathematical problems requiring addition, subtraction, multiplication, and division. Programmed instructions, stored in the computer's memory, coordinate all operations, time

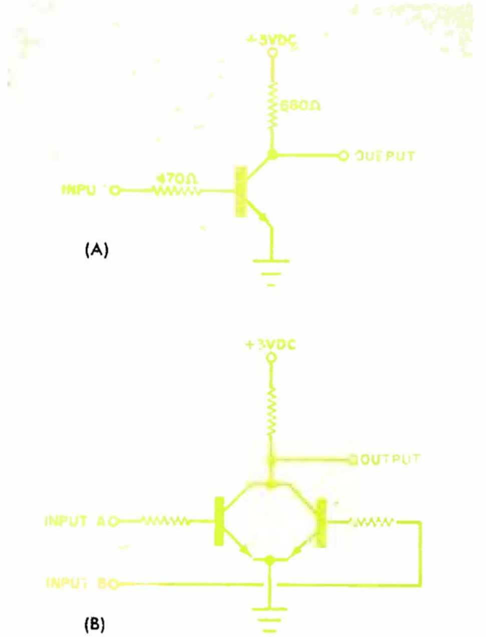



Fig. 6. NOT operation can be performed by a one-input RTL gate shown in (A). A two-input gate (B) can serve either as NOR or NAND circuit.

them for proper sequence, and route the information in the proper sequence to the various registers and output devices.

Logic gates can be constructed with such devices as relays, switches, tubes, and transistors. But in this era of microminiaturization, integrated circuits (IC's) offer the greatest advantage because they occupy very little space, consume little power, are extremely reliable, are quick-acting, and inexpensive.

Of the many varieties of logic IC's on the open market, the *resistor-transistor logic* (RTL) variety is probably the most popular. It can easily drive other

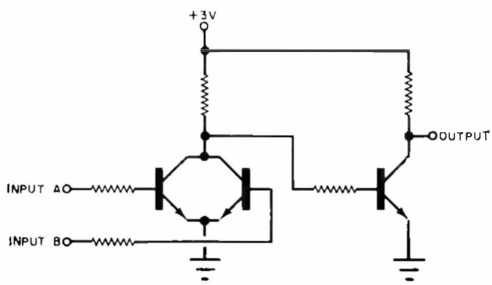



Fig. 7. The AND function is obtained by the addition of a NOT gate to output of a NAND gate.

IC's, and operates with voltage levels that are compatible with the requirements of external circuits. Typical one- and two-input RTL gates are shown in Fig. 6. If additional inputs are required, more transistors are added.

Operation of the gates is simple. If a transistor receives an input, it turns *on* to produce 0 output at the collector. The one-input gate, shown in Fig. 6(a), is the NOT circuit. If +3 volts are applied to the input, the output becomes 0. The absence of a voltage at the input produces +3 volts at the output. Observe that the output is always opposite in state to the input.

Now consider the two-input gate shown in Fig. 6(b). By first establishing that the presence of +3 volts at the input represents a 1, and the absence of this voltage represents a zero, the gate will function as a NOR gate since a 1 at either input produces a 0 at the output. If an OR gate is desired, a NOT circuit (one-input gate) can be added to the output to reverse the state.

If, on the other hand, it is established that the presence of +3 volts at the input represents a 0, while the absence of this voltage represents a 1, then the circuit will function as a NAND gate so long as the +3 volts appears on ***both*** inputs. Once again, the adding of a NOT circuit reverses the function to produce an AND response. See Fig. 7.

We can now proceed to build the "Logic Demon" around the circuits discussed so far by including a suitable selector switch and a transistor lamp-

## PARTS LIST

*B1—1.5-volt size "D" flashlight cell (2)*
*I1—3.2-volt, 160-mA pilot light (GE #1490 or similar)*
*IC1—Fairchild μL914 epoxy Micrologic dual two-input gate (Data sheet and list of distributors available from: Fairchild Semiconductor, 313 Fairchild Dr., Mountain View, Calif.)*
*Q1—Motorola MPS 834 transistor, or 2N834, or similar type (Data sheet and list of distributors available from Motorola Semiconductor, Box 955, Phoenix, Ariz. 85001)*
*S1, S2—S.p.d.t. switch or two-circuit NO/NC push-button switch*
*S3—4-pole, 5-position non-shorting selector switch (similar to Mallory 1325L)*
*1—5" x 4" x 3" cabinet (similar to Bud CU-2105A or Premier PMC-1005)*
*1—Metalphoto dialplate (optional)**
*1—Sealectro TS-800 IC 8-pin socket (available from Federated Purchasers, Inc., or Arrow Electronics, Inc., both in New York City)*
*Misc.—Battery holder, bracket for Q1 (optional—see text), bar-type knob, 5/16"-i.d. rubber grommet, transistor socket for Q1, nylon or rubber feet with hardware (4), rivets or screws for battery holder*

*Available from Reill's Photo Finishing, 4627 N. 11 St., Phoenix, Ariz. 85014: in silver color—$2.75: blue, red, or copper—$3.25: postpaid in the U.S.A.

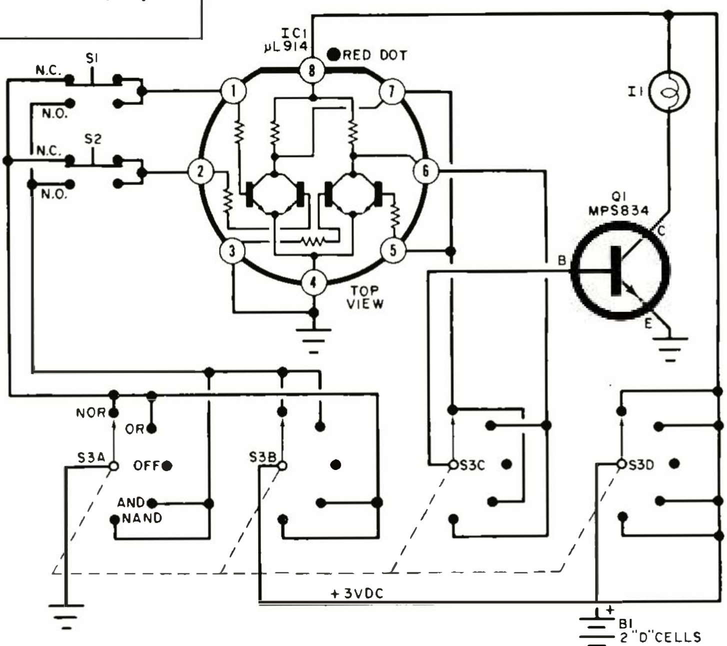



Fig. 8. Through exclusive use of dual two-input gate elements, any logic function can be generated from basic NAND/NOR gates in a fully integrated monolithic circuit.

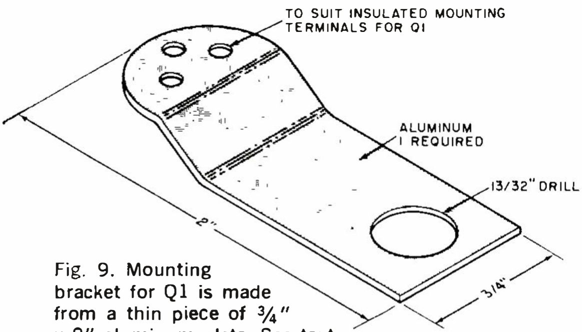
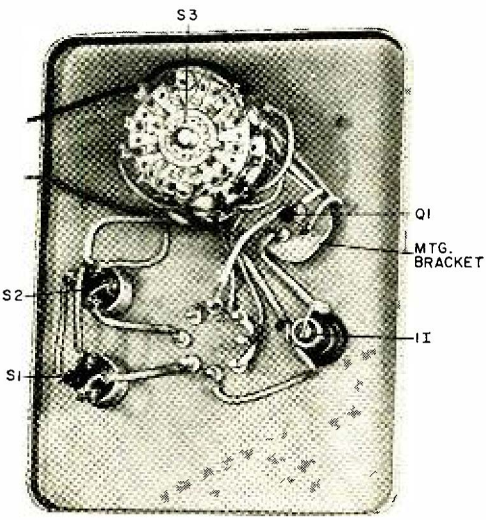


Fig. 9. Mounting bracket for Q1 is made from a thin piece of 3/4" x 2" aluminum plate. See text.

driver stage. After designing and building the Logic Demon, it can be used to perform real computer logic operations.

**About the Circuit.** The "brain" of the Logic Demon is integrated circuit *IC1* which contains dual RTL two-input gates (Fig. 8). One input is eliminated from one of the gates by grounding pin 3. Thus, a two-input gate and a one-input gate remain.

When the output (which drives *Q1*) is taken directly from the two-input gate, the circuit performs the NOR/AND functions. However, by feeding the output of the first gate to the one-input gate (which acts as an inverter or NOT gate) and then taking the output from the latter gate, the OR and NAND functions are obtained.



The Logic Demon can be wired using the schematic diagram and component layout shown in this photo.

A selector switch defines the input logic states and routes the lamp-driving transistor (*Q1*) to the appropriate gate output. If desired, separate slide or toggle switches can be used to produce the same logic functions.

**Construction.** The unit can be assembled on a metal chassis or in a wooden or plastic container. However, the use of a 5" x 4" x 3" metal box will give the project a neat appearance.

Except for the two dry cells which are mounted in battery holders that can be pop-riveted or screwed to the base, the switches, IC, and indicator lamp are mounted on the enclosure cover. If you use the prefabricated dialplate (see Parts List), the appearance of the project will be enhanced, and the dialplate can also serve as a drilling template for the holes that must be made in the cover to accommodate the switches, lamp, and the IC. The mounting hardware for the switches can be used to hold down the dialplate on the cover.

The IC shown here is mounted on individual Teflon insulated feedthrough connectors, but an alternate—and better—method is to use a single 8-pin Press-Fit IC socket as specified in the Parts List. Pin 8 of the IC case is usually coded with a red dot, or it may simply be beside the flat side of the case. Viewed from the top of the case, the pins are counted counterclockwise.

Transistor *Q1* is mounted on stand-off insulators inserted in a fabricated aluminum bracket (Fig. 9) which is secured on the inside of the enclosure cover by the rotary switch. However, this mounting procedure need not be followed since *Q1* can be mounted on a transistor socket in any convenient location in the enclosure.

The pilot lamp fits in a 5/16"-i.d. rubber grommet that mounts in a hole through the dialplate, and leads are soldered directly to the bulb. After making all the wiring connections (Fig. 8), you can proceed to test the unit.

**Operation.** If the unit is wired correctly, it will obey all the logic rules indicated on the dialplate. With the switch in the NOR position, the bulb lights and is extinguished by pressing either push

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## LOGIC DEMON

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button. In the OR function, the bulb lights when either push button is depressed, while in the AND function, both push buttons must be pressed at the same time for the light to come on. With the switch in an NAND position, both push buttons must be simultaneously pressed to put out the light.

The Logic Demon can be used in a classroom or at a Science Fair to demonstrate the practical application of computer (symbolic) logic. Granted that a number of individual switches could be used to perform the same function as the single IC package, it can be seen that the use of integrated circuits greatly simplifies the project. The Logic Demon also demonstrates some practical applications of the use of integrated circuits in computer technology. -30-

## "RELAXATROL"

(*Continued from page* 56)

bly. Slip a piece of spaghetti over each of the leads to insulate them and prevent short circuits.

Exercise care and work slowly when drilling holes in the plastic case. Use a file to shape the opening for the switch. A bottom cover for the case can be made from a thin piece of plastic or stiff cardboard, if you don't already have one. Two precautions should be taken: observe polarity of the diodes or proper connections of the rectifier module; and don't compromise the insulation—the rectifiers and *S1* are connected directly to the a.c. line.

**Operation.** When the unit is completed, check the wiring for any errors, then secure the bottom cover. Plug the a.c. line cord into a wall outlet and switch on the unit. After a slight delay, the relay should pull in and out at a regular interval. Rotate *R2* to change the interval. Range should be from very fast (approximately 15 seconds) to very slow (approximately 2 minutes). If desired,