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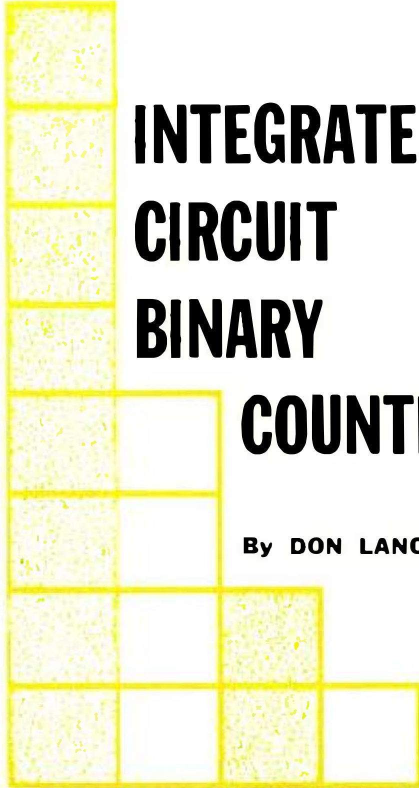
SCIENCE FAIR:
Build "Logic Demon" Binary Counter • Tesla's T

WANT TO BUILD AN

INTEGRATED CIRCUIT BINARY COUNTER?



By DON LANCASTER

10 = 1 0 1 0

COUNTING IN THE BINARY SYSTEM IS SIMPLE: YOU START WITH "ZERO, ONE" . . . AND YOU'VE USED UP ALL OF THE BINARY DIGITS

NOW you can build a demonstration binary counter using inexpensive integrated circuit (IC) industrial flip-flops with ordinary pilot lamps serving as readout devices. The binary counter described on the following pages can be used to demonstrate basic digital computer principles including the addition of binary digits. It also provides an opportunity to utilize integrated circuits for storing binary information.

In order to use the binary counter, however, you must understand the concepts of binary arithmetic. Most of us are familiar with the decimal number system which needs just 10 symbols—digits 1 through 9, and 0—to express any quantity. And while some earlier computers did use this system for computing, the complexity of the circuits dictated the need for a simpler system, one requiring fewer digits. So a number system using two digits only—1 and 0—was devised: the binary (base-2) number system.

Binary Number System. To learn how the binary (base-2) system works, consider Fig. 1 in which four groups of blocks are shown. The first one-block on the right is preceded by a group containing two blocks, which is preceded by a group containing four blocks, preceded by an eight-block group.

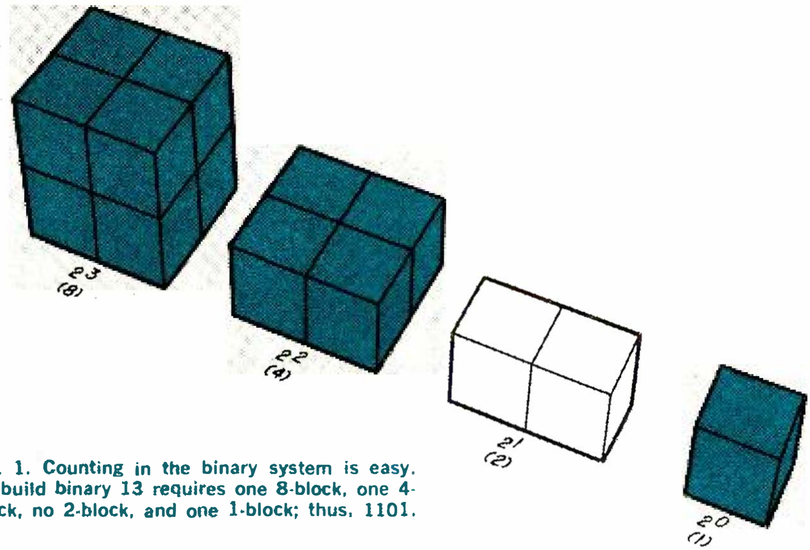


Fig. 1. Counting in the binary system is easy. To build binary 13 requires one 8-block, one 4-block, no 2-block, and one 1-block; thus, 1101.

Now, since we are working with a base-2 number system, we could change things a bit by writing the same group of blocks in this order: 2^3, 2^2, 2^1, 2^0. The superscript numerals (3, 2, 1, and 0) are referred to as the powers of the base number which, in this case, is 2. The power of a base tells the number of times the base must be multiplied by itself or, putting it another way, the power to which it is raised. For example, $2^3 = 2 \times 2 \times 2 = 8$. The mathematicians tell us that a number raised to its 0 power is 1; thus, 2^0 becomes 1. But we can also write: 8, 4, 2, 1 to represent the blocks.

To express 3 in the binary system, we need *no* 8 block, *no* 4 block, *one* 2 block, and *one* 1 block. In binary notation this is written as 0011. Similarly, the number 10 is written as 1010. And that is all there is to the binary number system.

The convenience of this system is immediately apparent, considering that any number in the decimal system can be converted to a series of 1's and 0's. Thus, to "write" a number on a punched card, you either have a hole or no hole—a 1 or a 0. Putting it another way, a YES or a NO. If lights are used as a readout device, it could be established that if the lamp lights it means a 1, and if it doesn't, it means a 0.

Binary Addition. Adding 5 and 3 gives us 8 in the binary system just as it does in the decimal system, except that the numerical process is different. The following decimal-to-binary conversion table will save you some time in working out a few examples of binary addition.

DECIMAL NUMBER	BINARY NUMBER
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111
8	1000

Three basic rules govern binary addition: (1) 0 plus 0 equals 0; (2) 1 plus 0 equals 1; and (3) 1 plus 1 equals 0 with a 1 carry to the next left-hand column. Applying these rules to the sample problem 5 + 3 will give you

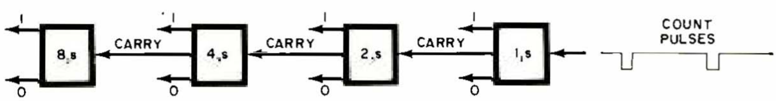


Fig. 2. This four-stage flip-flop has a counting limit of 15. Adding stages increases count capacity.

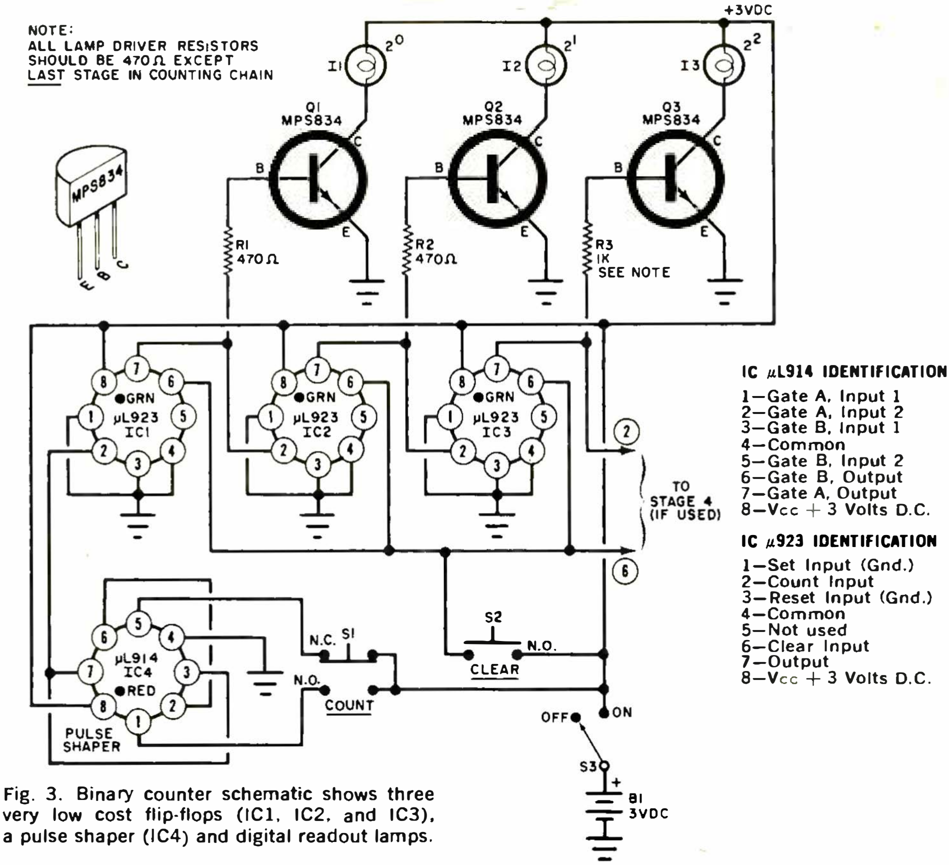


Fig. 3. Binary counter schematic shows three very low cost flip-flops (IC1, IC2, and IC3), a pulse shaper (IC4) and digital readout lamps.

PARTS LIST

B1—1.5-volt, C-size cells (2)
I1, I2, I3—#49 pilot light (2.0-volt, 60-mA)
IC1, IC2, IC3—μL923 epoxy JK flip-flop (Fairchild)*
IC4—μL914 dual two-input gate (Fairchild)*
Q1, Q2, Q3—2N834 transistor (Motorola MPS834)
R1, R2—470-ohm, ¼-watt resistor
R3—1000-ohm, ¼-watt resistor—see text
S1—S.p.d.t. push-button switch
S2—S.p.s.t. push-button switch
S3—S.p.s.t. slide switch
1—6" x 4½" x 1¼" aluminum box with cover (Zero Z64-104A-20 and Z64-104A-COT-5) or 5" x 7" x 2" box chassis (Bud AC-402)
1—METALPHOTO dialplate, hard anodized aluminum, with POPULAR ELECTRONICS trademark, available from Reill's Photo Finishing, 4627 N. 11 St., Phoenix, Ariz. 85014; in silver color for $2.75; blue, red, or copper for $3.25; postpaid in U.S.
1—2" x 3" sheet of aluminum or perforated phenolic board
1—1⅛"-diameter aluminum disc (optional—see text)
4—Sealectro 8-lead IC sockets for TO-5 case (optional, available from Arrow Electronics or Joseph Kurzan, Inc., both in New York City)
Misc.—Teflon insulated terminals (52, optional), insulated feedthroughs (4, optional); battery holder for two C-size cells, ½"-o.d. rubber grommets (3), pop rivets or #6 hardware, 6-32 x ⅜" threaded spacers (4), rubber feet (4), wire, solder, #6 mounting screws (4)

**Data sheets and distributor list available from Fairchild Semiconductors, 313 Fairchild Dr., Mountain View, Calif.*

$$\begin{array}{r} 101 \\ +\ 011 \\ \hline =1000 \end{array}$$

To define the above addition, starting with the right-hand column you have 1 + 1 = 0 with a carry of 1. Place the carry above the second column so that it now contains 1, 0, and 1. Thus, the second column is also 0 with a 1 carry. The carry added to the third column also produces a 0 with a 1 carry. Since there

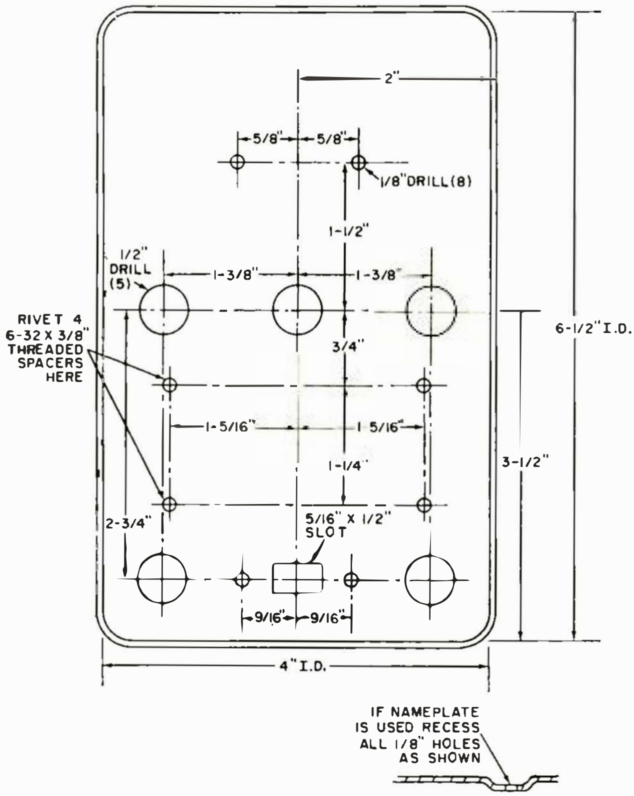


Fig. 4. You can use these dimensions to duplicate the front cover layout. Hole sizes should be made to accommodate your hardware and fittings.

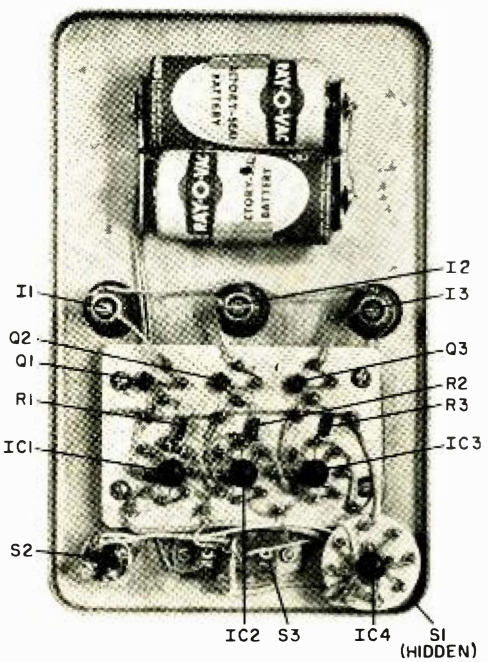


Fig. 5. The flip-flop IC's, and transistors and resistors, are first mounted on a subassembly supported on standoff spacers. IC4, shown on an aluminum disc, is supported by the push-button COUNT switch (S1).

is no fourth column in the problem, the carry is brought down as the fourth or most significant digit of the sum. The answer then becomes 1000 or 8.

When adding more than two binary numbers to produce a single sum, the numbers should be added in pairs. In other words, the sum of the first two numbers is added to the third number. The fourth number is then added and so forth until the last number is added to the sum of the previous two numbers to produce the total sum.

Electronic Counters. The essential difference between an electronic counter and earlier counters with mechanical wheels is that the electronic counters add pulses instead of gear teeth. But in addition to its ability to add, a counter must also have a way of storing the discrete digits representing the numbers.

A decimal counter, for example, must be able to store ten counts—0 through 9—before the next count resets the

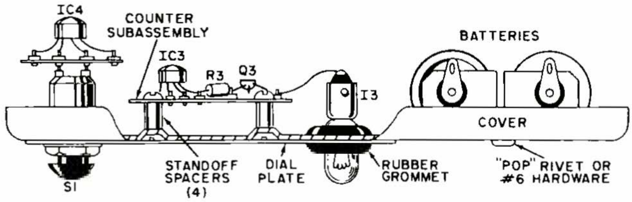


Fig. 6. This cutaway view of the front cover shows how the subassembly is mounted on the spacers. Observe that the mounting screw holes are recessed a bit so the dialplate can lay flat on the cover assembly.

counter to 0 with a 1 carry. Similarly, a binary counter is required to store only two counts—1 and 0—before it is reset. The electronic circuit used for counting is a simple flip-flop with its "set" state representing a 1, and its "reset" representing a 0.

The block diagram of a four-stage flip-flop binary counter that provides a count of up to 15 is shown in Fig. 2. Additional stages can be added to increase the count limits. For example, if one more stage is added, the count is increased to 31, while adding two more stages increases the count to 63.

During operation, pulses are applied to the count input of the 1's stage. A carry output from this stage is passed on to the count input of the 2's stage, and so on down the line to the last stage. With each incoming pulse, the 1's counter is alternately set to one, then reset to 0, set to 1 again, and so on.

The 2's counter also alternates between 1 and 0 each time it receives a count, but this happens only during every other input pulse when the 1's counter develops a carry signal. This process continues to activate each counter up to the last pulse in the string.

The IC Counter. Figure 3 shows the schematic of the IC counter. The innards of *IC1-4* have been deliberately left out to simplify matters. *IC1*, *IC2*, and *IC3* are the counting flip-flops, while *IC4* is a medium-power dual two-input resistor-transistor logic gate serving as a pulse shaper to eliminate the effects of contact bounce when the *COUNT* push button (*S1*) is pressed to produce the count pulses.

The modified output from the pulse shaper is applied to the count input of first counter stage *IC1*. The output of *IC1* is applied to the count input of *IC2*, whose output in turn is applied to *IC3*. Indicator lamps *I1* through *I3*, driven by *Q1* through *Q3*, visually denote the presence or absence of a 1 in each counting circuit. When a flip-flop circuit goes into its 1 state, a positive voltage is applied to the base of its respective output transistor through the proper base resistor (*R1*, *R2* or *R3*). The voltage causes the transistor to conduct, lighting the lamp.

Observe that *R3* is of a larger value than either *R1* or *R2*. If it were not so, lamp *I3* would burn brighter than *I1* and *I2* since *IC3*'s output is not loaded by the input of any other flip-flop, as is the case with *IC1* and *IC2*. Thus, if additional counting stages are added, bear in mind that the larger base resistor must appear in the last stage, although the base resistor of the other stages are of equal value.

CLEAR switch *S2* provides immediate reset capabilities by simultaneously applying a "1" pulse to the *CLEAR* input of each counter, resetting it to the 0 state.

Construction. The binary counter can be assembled in any small metal, wood, or plastic container. It is shown assembled in a 6" x 4½" x 1¼" aluminum box. A prefabricated METALPHOTO dialplate (see Parts List) can be put on the container cover to give the project a professional appearance. Layout and dimensions for drilling the cover are shown in Fig. 4. You can, however, lay out the counter differently, if you wish, since neither parts arrangement nor lead dress will affect operation of the unit.

Use a low-wattage soldering iron when assembling the unit to minimize the possibility of overheating and destroying the transistors and IC's. For ease of assembly, the IC's and transistor circuitry can be preassembled on a 2" x 3" aluminum plate, or phenolic circuit board. Then the plate or circuit board can be mounted on standoffs in the container cover. Interconnection is made from the

(*Continued on page* 90)

BINARY COUNTER

(Continued from page 61)

preassembled circuit board to the readout lamps, push-button switches, and supply battery.

The IC's and the transistors can be mounted on insulated Teflon press-fit terminals as shown in the layout of Fig. 5, or on "flea" clips (push-in terminals) if a perforated phenolic board is used. The use of regular 8-pin IC sockets and 3-terminal transistor sockets will provide greater ease of assembly, and reduce the possibility of the solid-state devices being damaged due to overheating at the terminals.

The IC packages are coded by a flat side or a green or red dot indicating pin 8. When viewed from the top, the pins are counted counterclockwise.

Figure 5 shows *IC4* mounted directly on one of the push buttons by means of a circular plate with feedthrough terminals, but you'll find it more convenient to mount *IC4* on the same circuit board with the other units.

Switch *S3* and the battery holder can be fastened to the case with #6 hardware, or can be pop-riveted in place. Switches *S1* and *S2* are mounted with hardware provided. The lamps are held by ½"-o.d. rubber grommets mounted in the holes provided. If a dialplate is used, it can be secured to the cover with the mounting hardware for the push-button switches. A cross-section view of the assembled unit (Fig. 6) shows mounting details of major components. Rubber feet can be attached to the container base.

Operation. Insert the batteries and flip the power switch to *ON*. With each depression of the *COUNT* push button, the binary count is advanced by one. To demonstrate binary addition, clear the binary counter to 000 with the *CLEAR* push button, and press the *COUNT* button to enter your first number. If it's a 2, enter binary 010 by depressing the *COUNT* push button twice. Now enter your second number. If it's a 3, enter 011 by pressing the *COUNT* push button three times. The answer 101 should appear on the readout lamps. –30–