ELECTRONIC BUILDING BLOCKS

PART 11

by R. A. DARLEY

LAST MONTH we discussed the monostable and bistable members of the multivibrator family, including the binary version of the bistable. This month we shall deal with the applications of this particular circuit.

BINARY SYSTEM

When using numbers for counting, adding, and multiplying, it is common practice to employ the decimal system based on the number 10, i.e. we use ten numerals, 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 as basic units, and we indicate the magnitude of any complete number by showing the numerals against a power of 10.

To give a specific example, the number 9278 is our shorthand way of saying 9000 + 200 + 70 + 8. All numbers are based on the power of 10; for example, $100 = 10 \times 10 = 10^2$. Similarly $1000 = 10^3$ and $1 = 10^0$. A number derived from powers of 10 is shown in Table 11.1. This number 9278 is equal to $(9 \times 10^3) + (2 \times 10^2) + (7 \times 10^1) + (8 \times 10^0)$.

TABLE 11.1. DECIMAL NOTATION

Powers	10^3	10^2	10^1	10^0
Decimal factor ...	1000	100	10	1
Decimal number	9	2	7	B

Unfortunately, transistors and other electronic devices do not have a convenient way of counting in powers of 10. All that the transistor can offer as the basis of a system of numbers is its alternatives of being either on or off, i.e. a choice of two states. Thus, the basic system that is used in electronics is based on the "power-of-two" or binary system. Table 11.2 gives the equivalent powers-of-two for decimal numbers, and the appropriate binary digits in the last line representing the decimal number 87, expressed in its binary form as 1010111. Note that the "power" table starts with "1" (expressed as 2^0 in the power-of-two series).

TABLE 11.2. BINARY NOTATION

Powers	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Binary factor ...	64	32	16	8	4	2	1
Binary number	1	0	1	0	1	1	1

In the coded section, a choice of only two numbers, either 0 or 1, are available. Using this table, other numbers may be expressed in binary form as shown by the following examples:

109 = 1101101   117 = 1110101
23 = 10111   11 = 1011

The highest number that can be derived from the above table is 127, i.e. twice the highest number (128) minus 1.

BINARY COUNTER CIRCUITS

The circuit that is generally associated with binary counters and dividers is the binary bistable multivibrator, shown in "block" form in Fig. 11.1a. Here, the elements that are of interest are the two output terminals, taken from the transistor collectors, and the single input terminal. The circuit may be any one of the binary types described in detail last month.

Assume initially that the transistor TR1 is off and TR2 is on; if *pnp* transistors are used, TR1 output terminal will be at near full negative potential and TR2 output terminal at near zero volts. Thus, if the negative potential is used to indicate a number, TR1 output terminal is indicating that "0" input pulses have been fed to the circuit.

When a positive input trigger pulse is fed to the circuit, the transistors will change state and TR2 output terminal will go negative, indicating that "1" input pulse has been fed to the circuit.

To indicate numbers greater than "1", binary units can be connected in cascade; Fig. 11.1b shows the connection of four such cascade units. The individual blocks are of the type just discussed.

The output at TR2 collector (b) of each block is used to supply the input trigger pulse for the following block: two input pulses are needed to give a single output trigger pulse from each block. Thus, one block divides by 2, two blocks divide by 4, three blocks divide by 8, and so on.

The table included in Fig. 11.1b shows the state of the circuit with succeeding input pulses. On each block, "1" indicates an "off" transistor (near full negative potential output at collector) and "0" indicates the on transistor (output at near earth potential). TR1 output terminals are indicated by (a) and TR2 outputs by (b).

The four block circuits shown give one output pulse for 16 input pulses, i.e. the circuit divides by 16. Note that, on the sixteenth pulse, the circuit reverts to the state as at "0" input pulses; the cycle of events then repeats itself again, and so on *ad infinitum*.

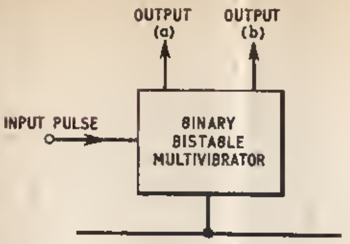
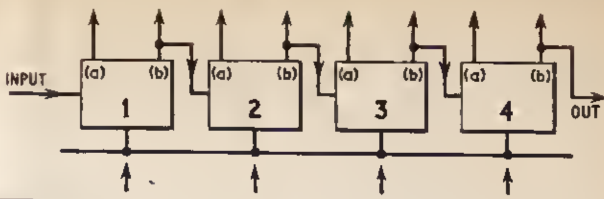


Fig. 11.1a (above). Block diagram of the binary bistable multivibrator



PULSE	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
PULSE 0	1	0	1	0	1	0	1	0
,, 1	0	1	1	0	1	0	1	0
,, 2	1	0	0	1	1	0	1	0
,, 3	0	1	0	1	1	0	1	0
,, 4	1	0	1	0	0	1	1	0
,, 5	0	1	1	0	0	1	1	0
,, 6	1	0	0	1	0	1	1	0
,, 7	0	1	0	1	0	1	1	0
,, 8	1	0	1	0	1	0	0	1
,, 9	0	1	1	0	1	0	0	1
,, 10	1	0	0	1	1	0	0	1
,, 11	0	1	0	1	1	0	0	1
,, 12	1	0	1	0	0	1	0	1
,, 13	0	1	1	0	0	1	0	1
,, 14	1	0	0	1	0	1	0	1
,, 15	0	1	0	1	0	1	0	1
,, 16	1	0	1	0	1	0	1	0

Fig. 11.1b (right). Four binary bistable circuits connected in cascade form. The associated table shows the state of the circuit with succeeding input pulses

BINARY "DECIMAL" DIVIDER CIRCUIT

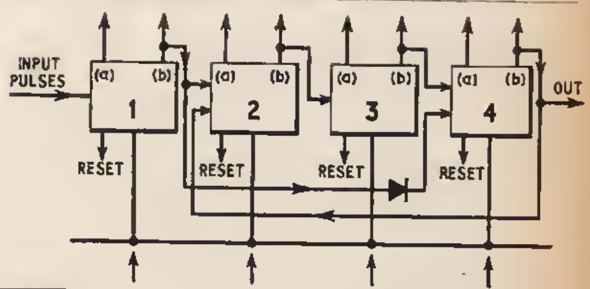
Whilst the binary system is the only one that the electronic circuit can basically work with, man finds it far more useful to use a "scale-of-ten" or decimal system; to be of any real use, therefore, the machine must be made to show results in a decimal form. As far as divider circuits are concerned, this means that the circuits must be made to divide by 10, as opposed to 8 or 16.

The circuit of Fig. 11.1b can be quite easily modified to give decimal operation, and Fig. 11.2 shows the block diagram in modified form.

Here, two feedback loops are included in the circuit, one taking the output from block 1(b) forward to the base of block 4(a), and the other taking the output of 4(b) back to the base of 2(a). A diode is included in the line from 1(b) to 4(a) connected in such a way that only positive going trigger pulses are passed, their purpose being to switch 4(a) off if it is turned on. During most of the working cycle of the circuit, 4(a) is switched off, so positive trigger pulses from 1(a) have no effect on this transistor.

Included in Fig. 11.2 is a table showing the state of the circuit with succeeding input pulses. Comparing this table with that of Fig. 11.1b, it can be seen that, up to and including the ninth pulse, the two circuits operate in an identical manner. In Fig. 11.2 it is the operation of the circuit on the tenth pulse that is of greatest interest. Note that, if the feedback loops were not included, block 2 would again switch on the arrival of this pulse; by including the feedback loops, however, the operation of the circuit is changed at this stage.

Before the arrival of the tenth pulse, block 4 had been switched, so that 4(a) is now on and is vulnerable to positive trigger pulses from 1(b) which will switch it off again; when the tenth pulse arrives, block 1 switches and sends the positive going trigger signal to 4(a), switching 4(a) off and 4(b) on; an output trigger pulse is thus made available at 4(b) output. The trigger signal from 1(b) output is coupled to 2(a) and tends to switch that transistor on; the output of 4(b) is coupled back to 2(a) base, however, and as



PULSE	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
PULSE 0	1	0	1	0	1	0	1	0
,, 1	0	1	1	0	1	0	1	0
,, 2	1	0	0	1	1	0	1	0
,, 3	0	1	0	1	1	0	1	0
,, 4	1	0	1	0	0	1	1	0
,, 5	0	1	1	0	0	1	1	0
,, 6	1	0	0	1	0	1	1	0
,, 7	0	1	0	1	0	1	1	0
,, 8	1	0	1	0	1	0	0	1
,, 9	0	1	1	0	1	0	0	1
,, 10	1	0	1	0	1	0	1	0

Fig. 11.2. Feedback loops convert the circuit in Fig. 11.1b to a "divide-by-ten" or "decimal" divider

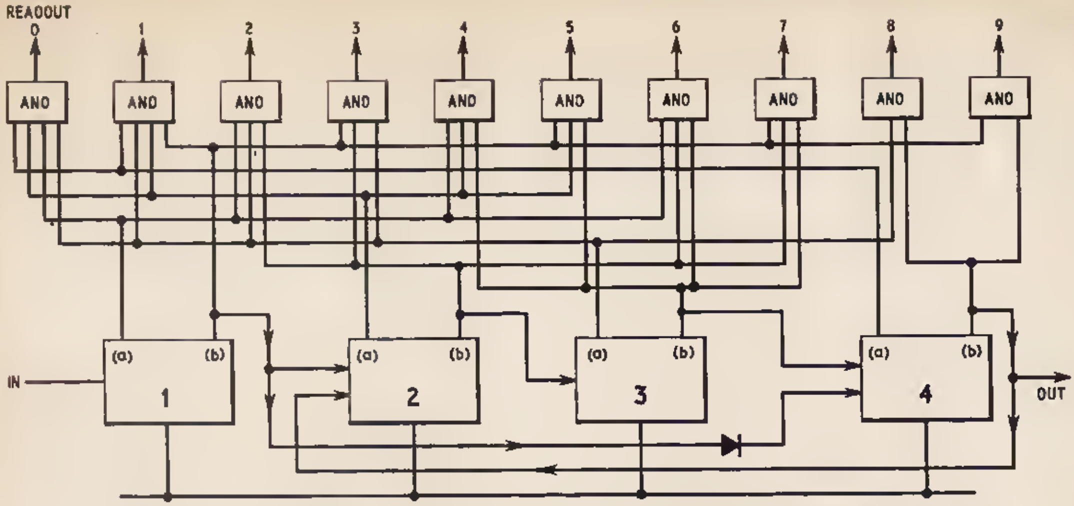


Fig. 11.3b. Combination of the four binary bistable circuits and the AND gate decoder

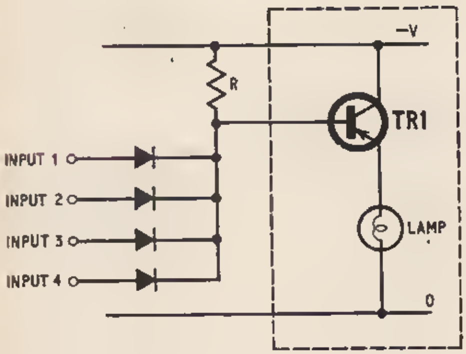


Fig. 11.3a. AND gate with readout facility

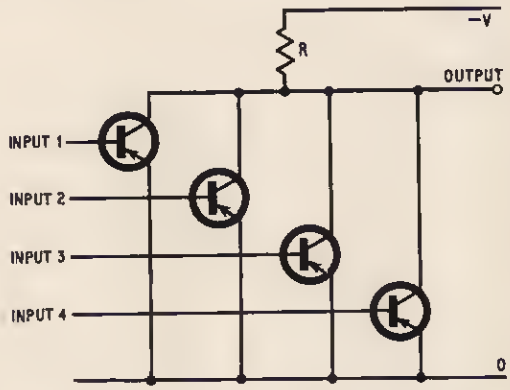


Fig. 11.4a. Basic circuit of a transistor NOR gate

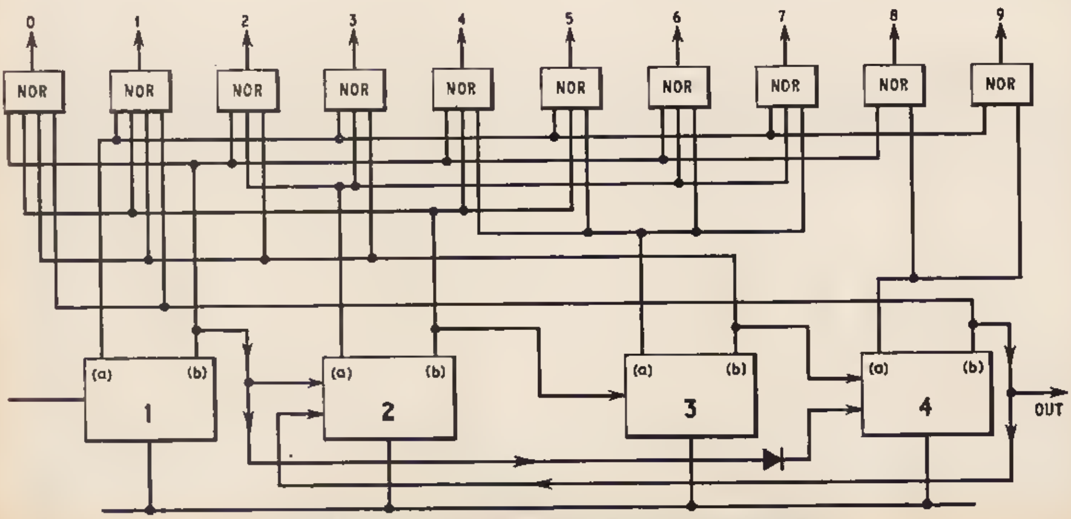


Fig. 11.4b. Complete decimal unit and NOR gate decoder

block 4 switches it sends back a signal to 2(a) base which countermands that arriving from 1(b). Thus, 2(a) remains off.

On the arrival of the tenth pulse, the circuit reverts to the condition it was at with no pulses; this condition, referred to as "reset", can be obtained artificially by applying a positive trigger pulse to TR1 transistors in all blocks simultaneously. This can be achieved by taking the "reset" terminals via a reset switch to a positive potential.

It may be noted that, although the "decimal" system described above is the most widely used type, it is not the only one in use; the feedback paths can be arranged in a number of ways; one manufacturer, for example, prefers to use a system in which the output of 4(a) is fed back to both 2(a) and 3(a) simultaneously. These alternative systems, as is so often the case with electronic circuits that have a wide number of variations, offer little or no advantage over one another.

COUNTING AND DECODING

So far we have considered the binary "decimal" unit purely as a divider, giving a single output pulse for every 10 input pulses; as often as not, however, the circuit is required to "count" the number of pulses fed into it and give a visual indication of that count in the decimal system.

Referring back to the table in Fig. 11.2, it can be seen that each individual input pulse begets its own set of transistor states, unique to itself. A count of three pulses is indicated by 1(b), 2(b), 3(a) and 4(a) outputs all being at near full negative volts; this condition of the circuit is unique to the third pulse. This, information is held in coded form in the circuit according to the number of pulses that have been counted. If suitable "decoding" circuits are used, this information can be translated into decimal form.

In principal, such "decoding" circuits are simple, but can be fairly complex in practice. Referring to the above example and to the tables, any given number within the range 0–9 inclusive can be represented by no more than four "bits" of information: for example, when negative potentials are available at 1(b), 2(b), 3(a) and 4(a) simultaneously, the number "3" is indicated.

GATE CIRCUITS

All that is needed, then, to indicate that number, is an electronic "gate" with four input terminals and a single output terminal, the circuit being so arranged that an output is available only when all four inputs are connected. The four input terminals must be connected to the relevant points on the counter unit, and the output terminal taken to a visual read-out device, such as a lamp. Such an electronic gate is known as an AND gate, for the simple reason that input 1 *and* 2 *and* 3 etc. must be connected before the output becomes available. Fig. 11.3a shows an example of the AND gate; to be more precise, a negative logic AND gate. The explanation of the gate circuit is a slight over simplification.

The four diodes and the resistor comprise the gate. For simplicity, assume that input signals will be either fully negative or at zero potential, and that the impedance of the resistor is high compared with that of the diodes. The output of the gate is taken from the junction of diodes and resistor.

If any one of the inputs to the gate is at zero potential, current will flow through that diode to the negative rail via the resistor; since the impedance of the diode is low, the output of the gate will be at near zero potential, due to the fact that the diode and resistor act as a potential divider.

Connecting two or more inputs of zero potential will cause little significant change to the output potential of the gate; conversely, connecting one or more of the inputs to a negative signal will make no difference to the gate output, since the zero potential input signal holds the output at near zero potential, and thus reverse biases those diodes that have the negative potential applied to their inputs. It is only when all inputs have negative potentials applied (no inputs at zero) that the output of the gate can rise to a significant negative value.

In Fig. 11.3a this negative output potential is shown as being used to drive a read-out unit (shown within the dotted square), which in this case is simply an emitter follower with a lamp as its emitter load; in practice, it is more likely that the transistor would be Darlington connected with another, to give a reasonably high input impedance.

Fig. 11.3b shows the block diagram of a complete decimal counting unit, and an AND gate decoding system and readout facilities. The basic binary "decimal" unit is the same as that shown in Fig. 11.2 and the table in Fig. 11.2 can be applied to both diagrams. A large collection of diode gates, as shown, is sometimes referred to as a "matrix".

ALTERNATIVE DECODING UNIT

In the case that we have just considered, the system relies on the negative potentials from the off transistors in the binary "decimal" unit to operate the decoding unit. An alternative system relies on the zero potential of the on transistors to give gate operation and decoding.

In this case the gates also have, say, four inputs and one output, but the negative output only becomes available when no negative inputs (or zero volts to all inputs) are applied. Such a gate is called a NOR gate, since the negative output is available when neither 1 *nor* 2 *nor* 3 etc. negative inputs are applied.

Fig. 11.4a shows the gate in basic form, but using transistors as active elements. Here, all transistors share a common collector load.

If a negative signal is applied to one of the inputs, its transistor will be biased hard on and the common collector, which also serves as the output of the gate, will fall to near zero potential.

If another negative input signal is applied to another input, all that will happen is that the current flowing in the common collector resistor will be shared between two transistors and the output of the gate will change by no significant amount. It is only when no negative inputs are applied, i.e. all inputs are at zero potential, that all currents are cut off and a significant negative output potential becomes available at the output of the gate. A number of variations of this gate exist, in some no transistors are used at all.

Fig. 10.4b shows, in "block" form, the connections used when employing the NOR gate decoding system with the binary "decimal" counting unit.

Next month: Counter/timer units, electronic gates, and triggering circuits