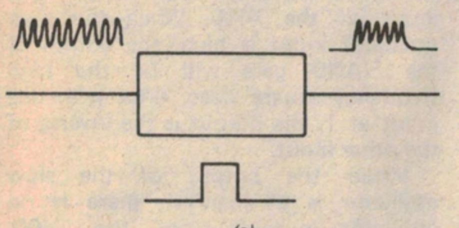
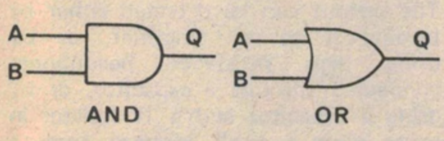
DIGITAL ELECTRONICS BY EXPERIMENT pt3

A GATE CIRCUIT, in general, is a circuit which will allow a signal to pass for a time defined by another signal, often a rectangular pulse (Figure 1a). In linear circuitry we need linear gates which do not affect the shape of the signal which is gated, but in digital circuitry, all the signals are steady voltage levels, 1 or 0, or fast transitions between these levels, so that speed of operation is important and *no* linear action is needed. Ideally, a perfect switch is also a perfect digital gate.

Logic gates are of two basic types, the AND the OR type. The simplest examples of each have two inputs and one output, though up to 13 inputs are found in some types. Taking the two input AND gate, the output is a logic 1 when, and only when, both inputs are also at logic 1 (A *and* B are at 1); the output is zero for any other combination of inputs. The two input OR gate gives a logic 1 output when *either* input is logic 1, or when both are at logic 1 (A *or* B both).



(a)



(b)

Fig. 1. Gates. (a) General gating action (b) Logic gate symbols.

AND–GATE		
A	B	Q
1	1	1
1	0	0
0	1	0
0	0	0

(a)

OR–GATE		
A	B	Q
1	1	1
1	0	1
0	1	1
0	0	0

(b)

Fig. 2. Truth tables. (a) AND-gate. (b) OR-gate.

These actions can be summarised in a truth table which shows at a glance what combinations of inputs and outputs are possible. Fig. 2 shows the truth tables for the AND and OR gates. Truth tables, though useful, become rather bulky when the gate has a large number of inputs, so that a better way of memorising the action is to remember that only when all inputs are 1 is the output of the AND gate 1, and only when all inputs are zero is the output of the OR gate zero.

NAND and NOR gates have outputs which are the inverse of the AND or OR gates respectively, as the truth tables of Fig. 3 show; internally these gates are AND/OR gates with inverters at the outputs. Another gate encountered at times is the exclusive-OR (XOR) which has the truth table and symbol shown in Figs. 3c, d. Note that the action is that of the OR gate, except that the output is 0 when both inputs are 1.

Working over a 7400

The second IC we shall deal with in this series is a 7400 quad NAND gate. This consists of four separate two-input NAND gates, and like all the other ICs used in this series is a TTL circuit. An unconnected input will therefore float to logic 1, and will need a current of 1.6 mA to be sunk to hold it down to logic 0.

Start work on this gate by connecting the power supply leads. Pin 7 is taken to the negative line by a wire connection, and pin 14 is similarly taken to the +5 V line. The connections to the gates are shown in Fig. 4; we shall start by using gate 1.

Connect a 470R resistor between pin 3 and a spare pad, as shown in Fig. 5.

NAND–GATE		
A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

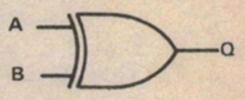
(a)

NOR–GATE		
A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0

(b)

X–OR GATE		
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

(c)



(d)

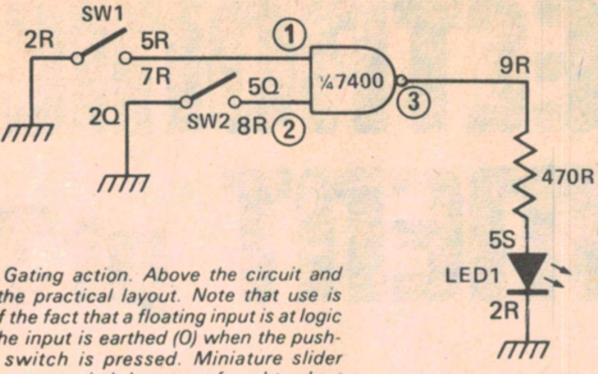
Fig. 3. Truth tables. (a) NAND-gate. (b) NOR-gate. (c) X-OR-gate. (d) Symbol for the X-OR-gate.

Now connect another LED between the spare pad and the zero line to act as an indicator to light when the output is at logic 1.

We could obtain inputs by soldering in wires, but this is rather tedious. Wire up the switches as shown in Fig. 5, wiring the terminals directly to the "0" line and the spare pads. Since these are press-to-make switches, their effect will be to give a logic 0 when pressed, the input to which they are connected will then float to logic 1 when the switch is released. Miniature slide switches were tried, but found to short 1 to 0.

With the switches in place, check the truth table for a NAND gate, using the LED to indicate the state of the output. The truth table should agree with that of Fig. 2a.

Now investigate the effect of adding an inverter, by joining a wire from pin 3 of the 7400 to pin 1 of the 7414, using the LED which is connected to pin 2 of the 7414 as the output indicator (Fig. 6). This connection, using the switches to provide inputs to the 7400, should give the truth table for an AND gate.



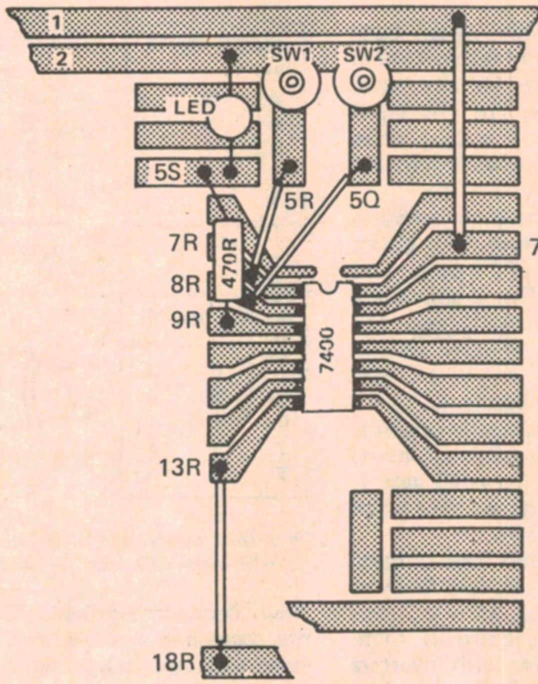


Fig. 5. Gating action. Above the circuit and below the practical layout. Note that use is made of the fact that a floating input is at logic "1". The input is earthed (0) when the push-button switch is pressed. Miniature slider switches were tried, but were found to short momentarily between the 1 and 0 positions.

We find, however, that if we invert each input before applying to the 7400 inputs (Fig. 7) that we do not obtain an AND gate this way. What truth table do we find?

To try it out, connect the switch outputs to the inverter inputs instead of to the 7400, one to pin 1 and the other to pin 3 of the 7414. Join pin 2 of the 7414 to pin 1 of the 7400 and pin 4 of the 7414 to pin 2 of the 7400, using single strand insulated wire. Use the LED which is connected to pin 3 of the 7400 as an indicator.

Having done this, could you design a NOR gate, and construct one? Try out your circuit and draw up a truth table.

The exclusive-OR circuit needs rather more thought. One possible circuit is shown in Fig. 8. Construct this, using the 7400 and 7414 units, and check that the truth table agrees with that of Fig. 3c.

Combinational Logic

Circuits which contain only logic gates are called combinational logic circuits, because the output can always be predicted from the combination of inputs which is present. As we shall see later in this series, there are circuits in which the previous inputs matter as much as the present ones. Combinational logic circuits obey the rules of Boolean algebra, which will not be dealt with here, but have been previously discussed in ETI.

Because the output can always be predicted from the inputs which are present, logic gates can be used for control circuits. We can, to take a simple example, control the heating of a house by having logic gates control the circulating pump (or fan), by way of a thyristor or triac.

The inputs to the gates will be the signals from room thermostats, perhaps an outside thermostat, a boiler thermostat, a hot-water tank thermostat, and a timeswitch or two. There will be another output from the gates to control the operation of the boiler.

For such a system, logic gates easily carry out AND and OR actions which would need much more wiring and space to carry out with relays, but the full advantage of using logic gates is obtained when all the thermostats and other signal generating equipment and timing are also electronic.

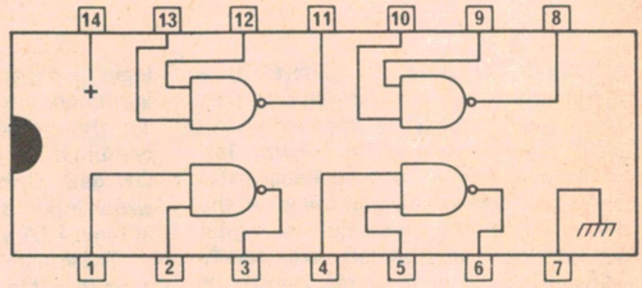


Fig. 4. Pin-out diagram for the 7400.

Bawdy Work

An application of gating is shown in Fig. 9, using the 7414 and 7400 to make a gated oscillator circuit. Two sections of the 7414 are used as oscillators, one at an audio frequency of about 1 kHz and the other at a much slower rate, and the outputs of the oscillators are taken each to one gate input of the 7400. When the slow oscillator input is high, the output of the NAND gate will be the high frequency square wave, since with one input at 1, the output is the inverse of the other input.

When the output of the slow oscillator is at logic 0, there is no oscillator output from the 7400, because the output is set to logic 1. The output can be detected either by feeding it to an amplifier, or by using high resistance headphones connected through a capacitor, or by using a capacitor and a 1k resistor in series with a small earpiece from a transistor radio.

Could you now design and construct a circuit whose output was a two-tone oscillation (HI-LO-HI-LO-). Remember that the output of the NAND gate in Fig. 9 was a logic 1 when not oscillating. Do NOT be tempted to combine the outputs of two gates by joining output pins; this will BURN OUT YOUR IC, because very large currents will flow if one output is at 1 and the other at 0. One possible scheme uses three of the 7414 inverters as oscillators and one as an inverter, with three NAND gates also used.

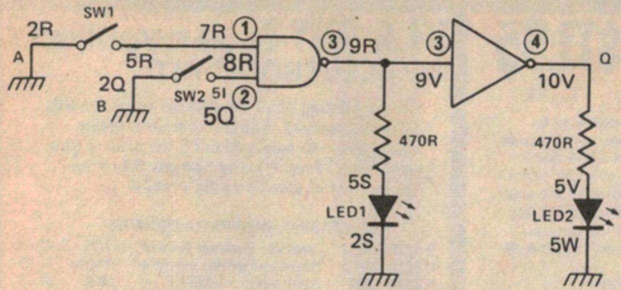


Fig. 6. Using a NAND-gate and an inverter to make an AND-gate.

very short, but not too short for a counter to detect and register. Race hazards will not affect any of the circuits in this series, and the avoidance of race hazards is a topic which is beyond the scope of our work at present.

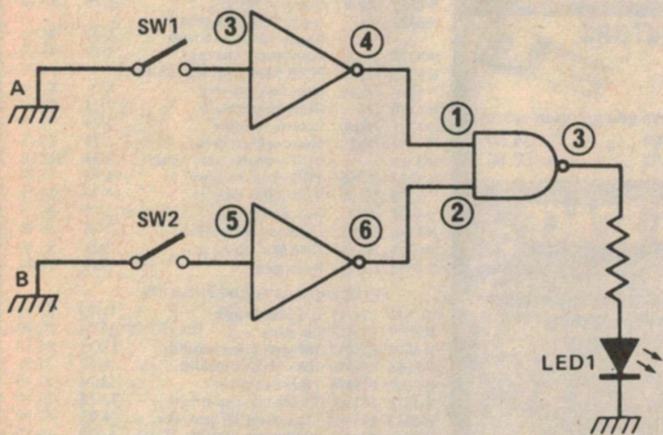
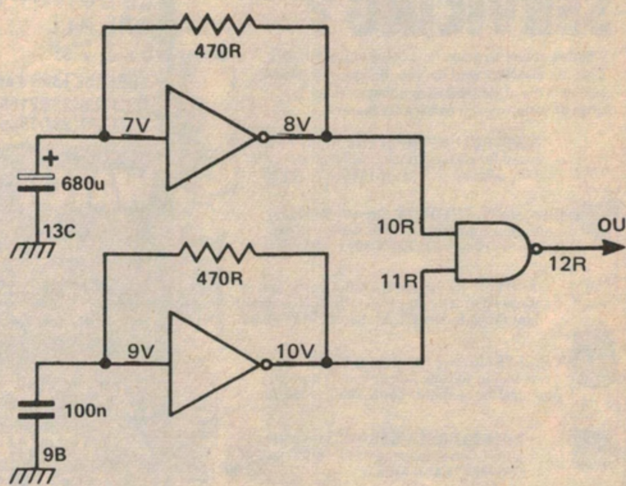


Fig. 7. What is the truth table for this circuit?



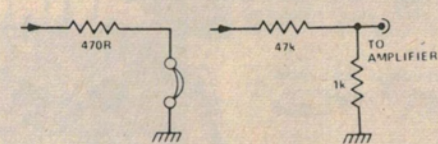


Fig. 9. A gated oscillator. (a) Circuit. (b) using an earphone to detect the note. (c) Connecting the output to an amplifier.

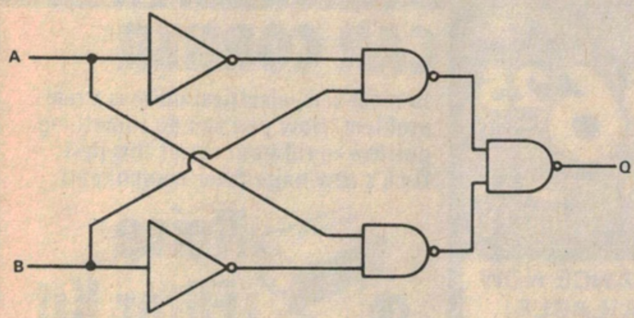
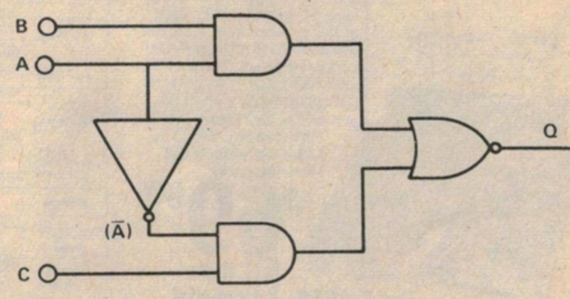


Fig 8. An exclusive-OR gate built from NOR-gates and inverters.

Racy Hazards

One problem of combinational logic circuits is the short but measurable time delay (some 30-80 ns) which occurs in a gate, which can cause momentary spikes to appear in the outputs. A circuit which can give such a problem is shown in Fig. 10. Imagine that B and C are both 1 and that A is changing from 1 to 0. With B and C at 1, the output of the circuit is A or A, and since A is obtained from an inverter it will arrive at the OR gate a little later than A. Momentarily, then, A will be at 0, and A will still be at 0, so that the output will dip to 0, and then rise to 1 when A arrives. The pulse will be



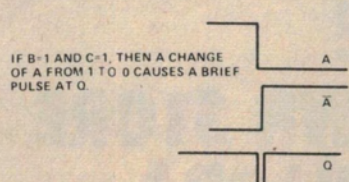


Fig. 10. Race hazards. If we imagine that lines B and C are both at one, then the change from A = 1 to A = 0 should cause no change in the output. Because of the delay in the inverter, however, A goes low just before Ā goes high so that there is a narrow negative pulse developed at the output. This could cause problems if a counter were being driven from the output.