

Digital Electronics

Objectives

To investigate the fundamentals of digital electronics, including logic gates, flip-flops and counters.

Apparatus

breadboard with power supply
a collection of digital ICs
connecting wires
digital voltmeter
an oscilloscope
a function generator

Introduction

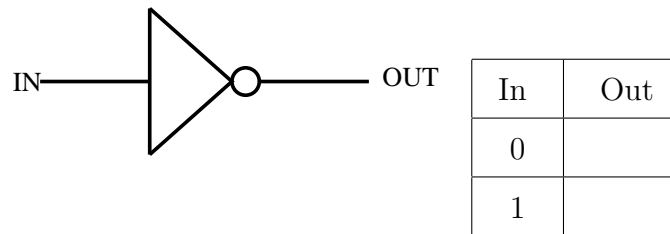
Digital electronics is based on the binary number system and found in everything from computers to CD players and watches. Instead of voltages which vary continuously, as in analog electronics, digital circuits involve voltages which take one of only two possible values. In our case these are 0 and 5 volts (TTL logic), but they are often referred to as LOW and HIGH, or FALSE and TRUE, or as the binary digits 0 and 1.

The basic building blocks of digital electronics are logic gates which perform simple binary logic functions (AND, OR, NOT, etc.). From these devices, more complex circuits can be constructed to do arithmetic, act as memory elements, and so on. Here, you will look at a few basic devices to see what they can do.

Logic gates and other digital components come in the form of integrated circuits (ICs) which consist of small semiconductor “chips” packaged in a ceramic or plastic case. The ICs are labelled by numbers like $74LSxx$, where xx is a number identifying the type of device. The pin connections for most of the devices used in this experiment are posted in the laboratory; more details about the circuits can be found on line or in reference books [1] or [2].

Logic Gates

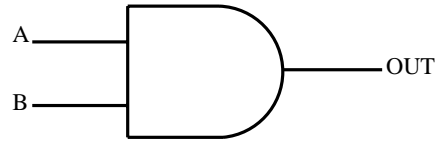
The 7404 chip contains six *inverters*. An inverter simply converts binary 1 to 0 and vice versa. Insert a 7404 chip into the breadboard and connect pin 7 to ground and pin 14 to 5V. (Make sure that all of the pins are properly seated in the sockets rather than bent underneath.) Connect one input to a switch so you can easily set it to 1 or 0, and connect the corresponding output to one of the LED indicators provided. Confirm the functionality of the inverter. Make a “truth table” which shows the output of the circuit for each possible input state. For the inverter, the truth table is pretty trivial. The symbol for an inverter and its (incomplete) truth table are shown below.



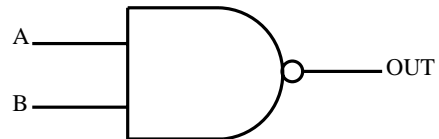
Connect the output to a DMM and note the values of the voltages which correspond to 1 and 0. Repeat this exercise for the gates shown overleaf.

Many logic chips have several identical gates on them. The circuit designer may find that there is a need for a certain type of gate while, at the same time, there are already a number of unused gates of a different sort in the circuit. It is then useful to know how to use one type of gate to obtain the logic function of another. How could you use a NOR gate as an inverter? Design and construct NAND and AND gates made entirely from NOR gates.

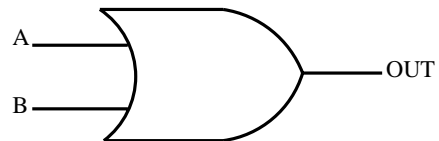
AND gate (7408)



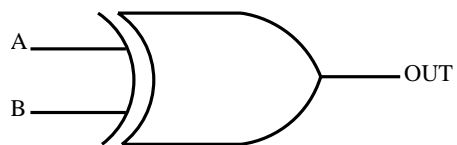
NAND (= NOT AND) gate (7400)



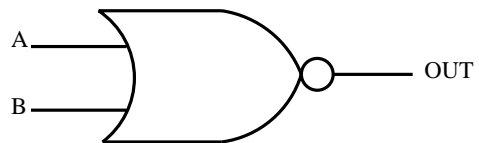
OR gate (7432)



XOR (exclusive OR) gate (7486)



NOR gate (7402)



Adders

A “half-adder” adds two one-bit binary numbers, x and y , and has the following truth table where S means “sum” and C means “carry”:

x	y	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

The S column looks like the truth table for an XOR gate while the C column looks like that of an AND gate. Given this, design and build a half-adder. Following this, design and build a “full-adder” which takes *three* inputs, x , y , and C_0 , where C_0 is the carry bit from a previous addition, and produces two outputs, S and C_1 so that $x + y + C_0 = S + C_1$. (Hint: Think about how you could combine the S' and C' outputs of an $x + y$ half adder with C_0 to get the S and C_1 truth table for a full adder.) Full-adders can be cascaded together to add binary numbers with any number of bits.

Flip-flops

A flip-flop is a circuit with “memory” in that it can be set to remember a given output value. A commonly used flip-flop is the JK flip-flop, 7473. It has four inputs. One of these is a RESET and one is called CLOCK. The other two, J and K , can be set to control how the flip-flop outputs, Q and \overline{Q} , behave when the CLOCK input is changed. Here is a partial truth table:

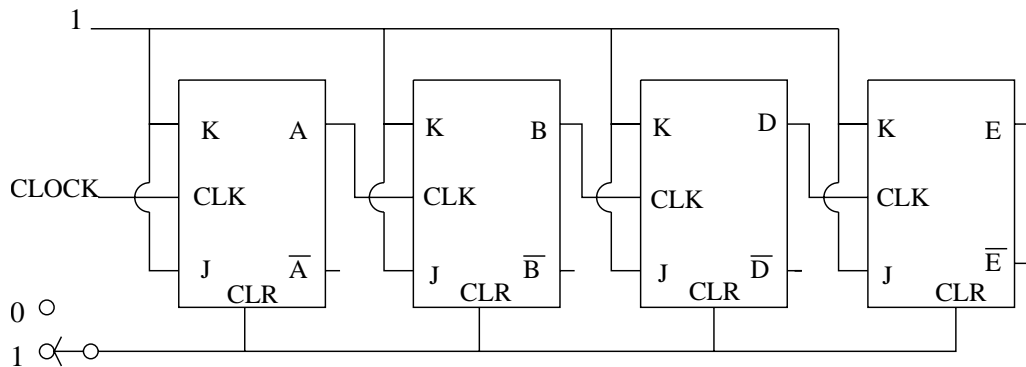
INPUTS				OUTPUTS	
RESET	J	K	CLOCK	Q	\bar{Q}
1	0	0	transition		
1	0	1	transition		
1	1	0	transition		
1	1	1	transition		
0	–	–	transition		

Investigate how the JK flip-flop behaves when the clock input changes and fill in the truth table. Note that the outputs will change, if they change at all, when the CLOCK goes from 1 to 0. You can also use a 7476 flip flop with the PRESET input connected to 5 volts.

Counters

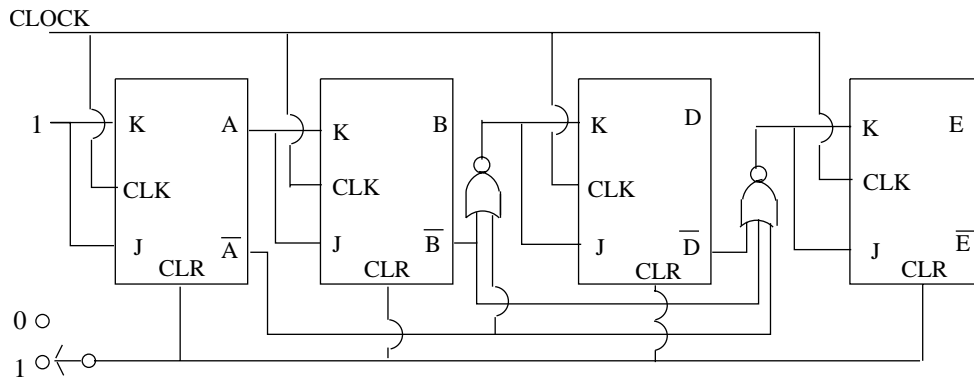
Flip-flops and gates can be used to build counters of various types. We first consider a binary counter made from four flip-flops as shown below. Connect the Q output of each flip-flop to an LED indicator. Pulse the CLOCK input and verify that this counter counts, in binary, up to $2^4 - 1 = 15$. **Explain how it works.**

An asynchronous binary counter.



The above counter is asynchronous meaning that the bits don't all change simultaneously. It has the advantage of simplicity but may not be appropriate when either high speed or precise timing is necessary. Using a square wave to CLOCK the counter and an oscilloscope to observe the outputs, draw a reasonably accurate timing diagram showing the relationship between the clock signal and the four outputs. Indicate which are the most and least significant bits. If you observe any delay between the clock pulse and the counter response, indicate it in your diagram. The next counter is a synchronous binary counter. Assemble it and explain how it differs from the previous counter.

A synchronous binary counter



Decade Counter

Computers use binary arithmetic but people are more comfortable with decimal. Using a few gates, it is possible to construct a decade or base-10 counter. A decade counter can be constructed in a similar way to the (a)synchronous counters you built earlier, using J-K flip flops. The circuit for a decade counter is shown below. Build it and confirm its operation. Note that $D + AE$ is equivalent to the logical expression “ D OR (A AND E)”

Instead of the implicitly binary LED indicators (they are either on or off), we can use a 7-segment LED display to display decimal digits. The display modules provided in the lab include a decoder chip which takes a 4-digit binary number from a counter and converts it to a set of voltages on a subset of seven pins corresponding to the appropriate subset of the seven segments in the display. Replace the LED indicators with a 7-segment display (7447).

Counters are sufficiently common that they are built into their own ICs. One example is

References

1. *Logic and Memory Experiments using TTL Integrated Circuits, Vol I and II*, P. R. Rony (Sams, Indianapolis, 1979).
2. *The Art of Electronics*, P. Horowitz and W. Hill (Cambridge, 1989).