Experiment 1. Logic Gates

Masud ul Hasan · Ahmad Khayyat – Version 151, 5 March 2015

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1. Objectives

- Introduce logic gates
- Identify, test, and use integrated circuit chips (ICs).

2. Materials Required

- ICs: `7404`, `7408`, `7432`, `7486`
- Wires
- Wire stripper
- Breadboard
- IC tester

3. Background

3.1. What is Digital Logic?

- Digital logic describes the operation of *binary* systems: 2-valued systems, or systems where only two values are possible; *true* or *false*.
- Variables in binary systems are *binary variables*. They can assume one of only two possible values; *true* or *false*.
- In digital circuits, the *true* value is represented by a *high* voltage while *false* is represented by a *low* voltage.
- Common alternative representation for these two values are `1` and `0`, alternatively called *true* and *false*, respectively.
- Digital logic operations are governed by a special algebraic system named *Boolean algebra*. Compared to normal algebraic operations, logic operations operate only on *binary variables*.

- Boolean algebra defines three basic Boolean operations: AND, OR, and NOT.
- In digital circuits, Boolean variables are represented by electronic signals. Boolean operations on these variables are performed by electronic circuits referred to as *logic gates*.

3.1.1. AND Gate

Given two statements, *a* and *b*, where each statement can only be either true or false, we can say that *statement a* AND *statement b* are true only if *statement a* is true and *statement b* is also true. Thus, AND-ing two true statements results in a true statement.

In digital logic, the output of an AND gate is true (high) only when *all* of its inputs are individually true (high).

To describe the AND operation, we use a *truth table*. The truth table of a gate specifies the value at the output of the gate for each possible input combination. For *n* inputs, the number of possible input combinations is 2^n. The truth table for the two-input AND gate is shown below.

Table 1. AND gate truth table

in1	in2	out
F	F	F
F	T	F
T	F	F
T	T	T

3.1.2. OR Gate

The OR gate output is *true* if *either* input is *true*.

Exercise

Fill in the truth table below of the OR gate.

in1	in2	out
F	F	F
F	T	T
T	F	T
T	T	T

3.1.3. Two-Input XOR Gate

A two-input XOR gate outputs a value of *true*, or *high*, if its two inputs are different, and outputs a value of *false*, or *low* if the inputs are the same, i.e. both *true* or both *false*.

Exercise

Fill in the truth table below of the two-input XOR gate.

in1	in2	out

3.1.4. NOT Gate

Another important logic gate is the inverter or the complement, also known as the NOT gate. It negates the input value; turning an input whose value is *true* to an output of value *false*, and vice versa.

Exercise

Fill in the truth table below of the NOT gate.

in	out
	T

3.1.5. NAND, NOR, and XNOR Gates

The NAND gate is a combination of the AND with the inverter (NOT gate) connected at its output. The NAND gate is the reverse or *complementary* form of the AND gate. It is also a *universal* gate because it can implement all other basic gates.

Similarly, the NOR gate is equivalent to an OR gate with an inverter at its output. It is the complementary form of the OR gate, and is also a universal gate.

The XNOR gate is equivalent to an XOR gate with an inverter at its output, and is the complementary form of the XOR gate.

3.2. Logic Gate Integrated Circuits (ICs)

The 7400 series of transistor-transistor logic (TTL) integrated circuits (ICs) contains hundreds of devices, including the basic logic gates discussed above. A given IC from this family has a specific number that starts with `74`, followed by a few optional letters, then two or three digits. The letters are related to some characteristics of the IC electronics. For example:

`L` Low power (compared to the original TTL logic family), very slow

`LS` Low power Schottky (named after the German physicist Walter H. Schottky)

`AS` Advanced Schottky

`ALS`	Advanced low power Schottky
`F`	Fast (faster than normal Schottky, similar to AS)
`C`	CMOS
`HC`	High-speed CMOS

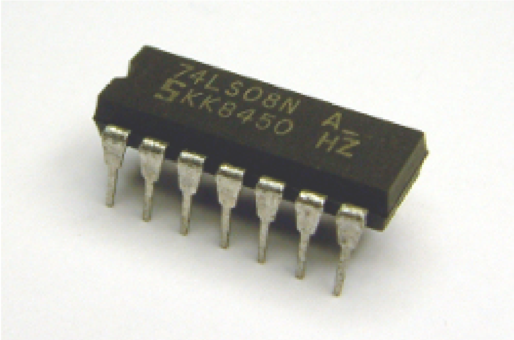

Figure 1. An AND Gate IC (`7408`)

The last two (or three) numbers are the important part that indicates the function of the IC. For example:

`74xx04`	NOT gate
`74xx08`	AND gate
`74xx32`	OR gate
`74xx86`	XOR gate

> The 5400 series of ICs is functionally similar to the 7400 series. For example, both 7408 and 5408 ICs are quad 2-Input AND gates. The difference is that the 7400 series is consumer-grade, whereas the 5400 series is for military applications.
>
> The 5400 series ICs tolerate a wider supply voltage, work in wider temperature ranges, and have better noise immunity. They are also more expensive. The operating temperature range for the 5400 series is -50°C to 125°C, while the 7400 series range is from -40°C to 85°C. Similarly, the 5400 series can be operated in the voltage range 4.5V to 5.5V, while the 7400 series can be operated in the voltage range 4.75V to 5.25V.

3.3. Breadboards

A breadboard is a reusable base board used to prototype and experiment with electronic circuits without soldering any components. The small breadboard figure shows a small breadboard. The holes in the board are connected as shown in the breadboard connections figure. For example, all the blue holes in section `A` in the breadboard connections figure are connected, such that connecting any one of them to a `GND` terminal will result in them all acting as `GND`. Sections `A` and `D` in the figure are typically known as the power rails. In a larger broardboard, such as the one shown in the large breadboard connections figure, there may be multiple, disconnected power rails. Breadboards make it convenient to connect components and build circuits.

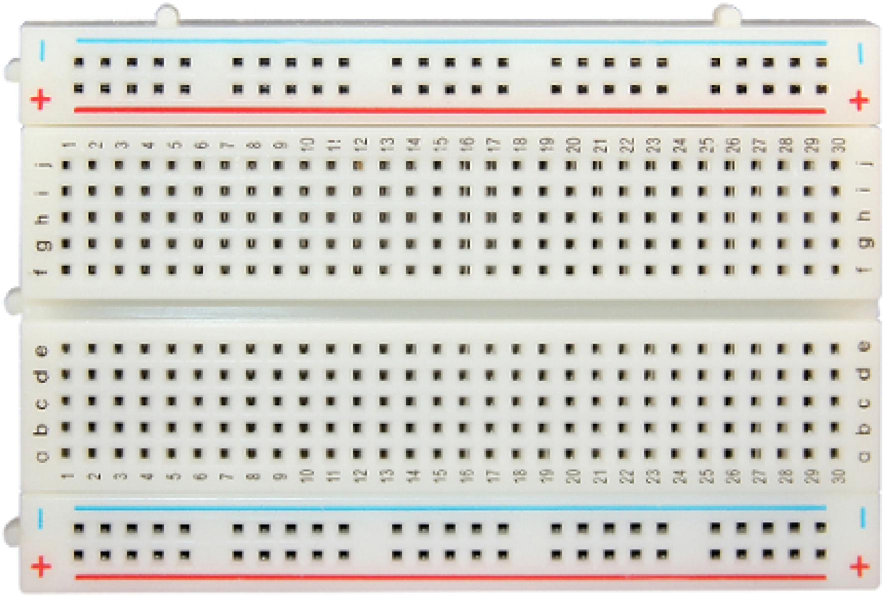

Figure 2. Small breadboard

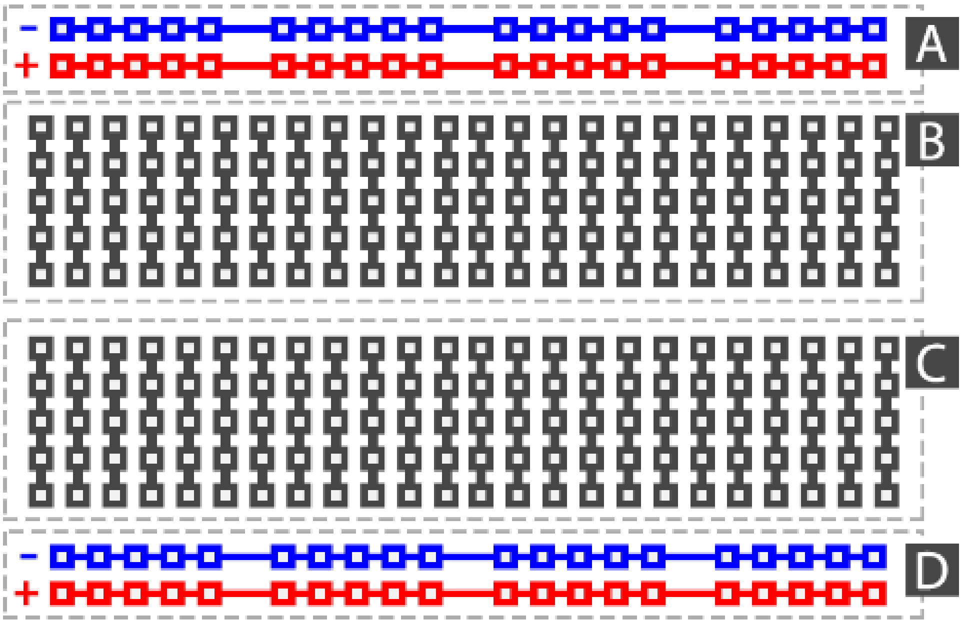

Figure 3. Breadboard Connections

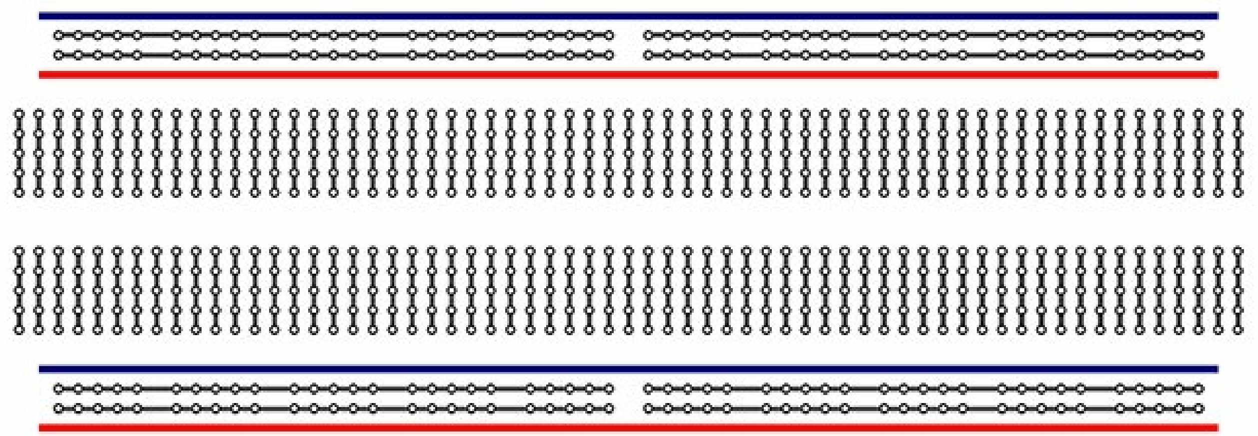

Figure 4. Large Breadboard Connections

3.4. Using ICs with a Breadboard

To use an IC, you refer to its *datasheet*. The pin layout is an essential part of any datasheet that specifies the function of each pin. As an IC contains electronic circuits, it needs to be powered by connecting an external power source, such as a battery, to the IC power terminals (pins). These pins are usually called *Vcc* (or *Vdd*) and *GND* (or *Vss*). An IC also has input and output pins.

Below are the pin layouts of the NOT IC and the 2-input AND, OR, and XOR ICs.

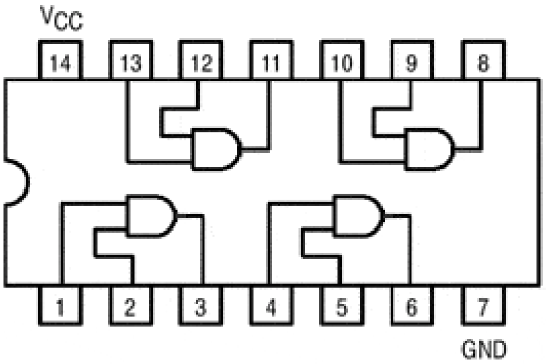

Figure 5. `7408` *: Quad 2-Input AND Gates*

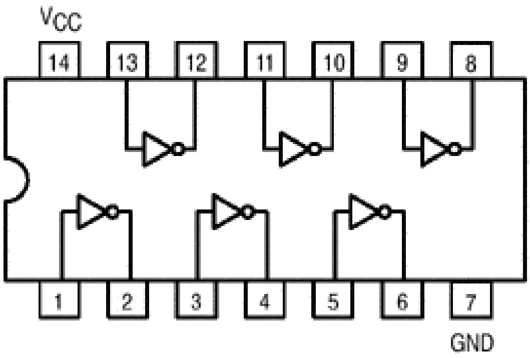

Figure 6. `7404` *: Hex Inverters (NOT)*

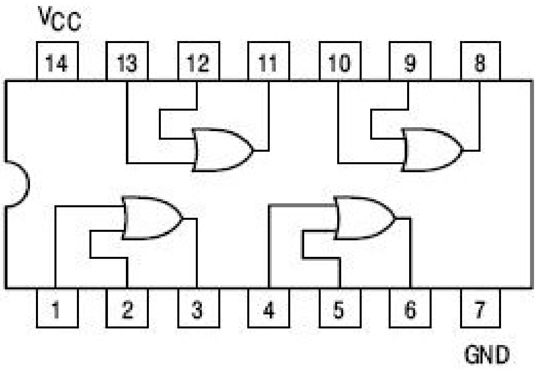

Figure 7. `7432` *: Quad 2-Input OR Gates*

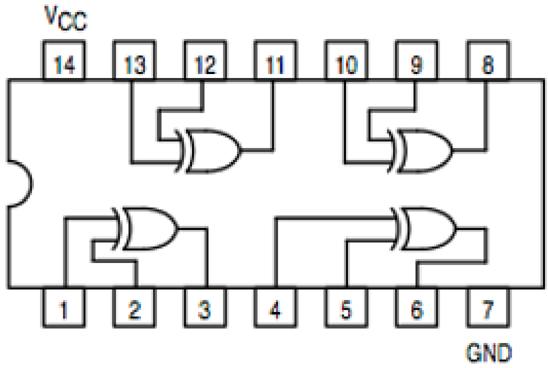

Figure 8. `7486` *: Quad 2-Input XOR Gates*

The [example circuit on a breadboard figure](#) below shows how components can be interconnected using a breadboard.

> To test a circuit, you would want to apply known inputs, observe the resulting outputs, and compare them to the expected outputs.
>
> A common way to apply a binary input is to use a switch, and a common way to observe a binary output is to use an LED.

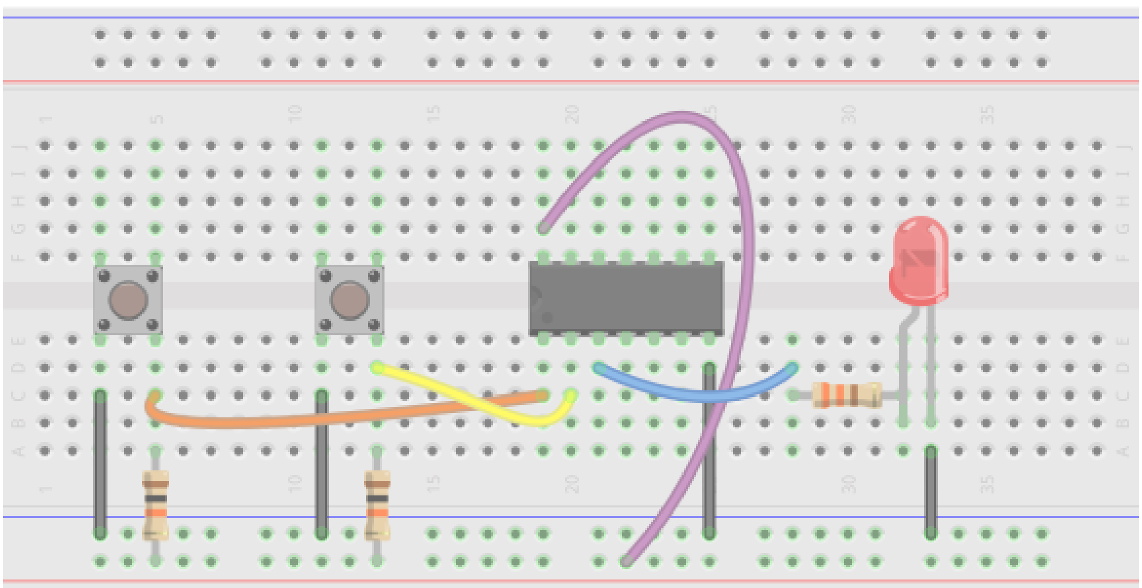

Figure 9. Example Circuit on a Breadboard

Exercise

In the [example circuit figure](#), assume that the IC is `7408`.

1. Which wire color should be connected to `Vcc`, and which color should be connected to `GND`?
2. What does this circuit do? and when will the LED light up?

4. Tasks

4.1. Verifying the Truth Tables

1. Complete the truth tables of the 2-input AND, NOR, and XOR gates.
2. Verify the truth tables by implementing these three gates on the breadboard using the ICs for the AND, OR, XOR, and NOT gates.

   To use an IC:

   a. Test it using the IC tester.
   b. Place it on the breadboard carefully.
   c. Connect its `Vcc` and `GND` pins to a `+5V` power source and a ground terminal, respectively. Use the power rows on the bread board for easy access to these two signals.
   d. Use switches to control the inputs, and LEDs to observe the outputs.

4.2. Building a 4-Input AND Gate

1. Build a 4-input AND gate using 2-input AND gates (`7408`).
2. Verify the truth table of the 4-input AND gate.

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5. Grading Sheet

Task	Points
Verifying the truth tables of AND, NOR, and XOR gates	35
Building a 4-input AND gate	40
Lab notebook and discussion	25

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