02 | combinational logic circuits

1. Overview

This laboratory will require the construction of a combinational logic circuit using discrete components (integrated circuits, ICs). The output of the circuit will be compared against a manually-derived truth table. One of the main laboratory objectives is to introduce troubleshooting techniques when the output of the circuit does not match the predicted circuit behavior, in addition to familiarizing the student with typical ICs and circuit construction techniques used in digital circuit design.

2. Objectives

At the conclusion of this lab, the student will be able to:

1. Interpret IC data sheets to determine gate input and output pins.
2. Wire standard 74xx series gate ICs based on a provided design.
3. Interface standard ICs to light-emitting diodes (LEDs) to test logic designs.
4. Use current-limiting resistors for proper operation of LEDs.
5. Use pull-down resistors and switch banks for inputs to the circuit.
6. Interpret and explain experimental results, based on the behavior of a logic circuit.
7. Develop basic troubleshooting skills for manually wired circuits.

3. BACKGROUND

Integrated Circuits

Although it is possible to construct digital circuits using discrete transistors, integrated circuits (ICs) offer a way to get a much lower cost, lower power circuit that is less prone to any mechanical or electrical interference. Some ICs today offer millions of transistors packed into a small 1x1 cm square of silicon. The ICs that will be used in this laboratory are in the dual in-line package (DIP) format, ready to be placed onto a breadboard. **Fig. 3.1** demonstrates a typical DIP IC.

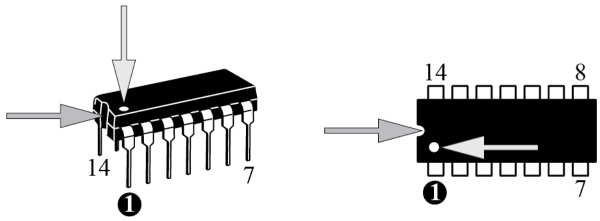

Fig. 3.1. Pin 1 markings on standard DIP ICs.

Most ICs have pin 1 marked by a deep notch in the middle of the chip or a small indentation near pin 1 (or both), as shown in the above figure. The function of a particular IC can be determined by reading the corresponding datasheet for the device. For example, the datasheet for an inverter IC (the NOT gate) can be found on the internet by searching for "74HC04", which is the part number for this IC. Typically, datasheets from Texas Instruments, National / Fairchild / NXP / ON Semiconductor, or Motorola / Freescale are considered to be authoritative and reliable.

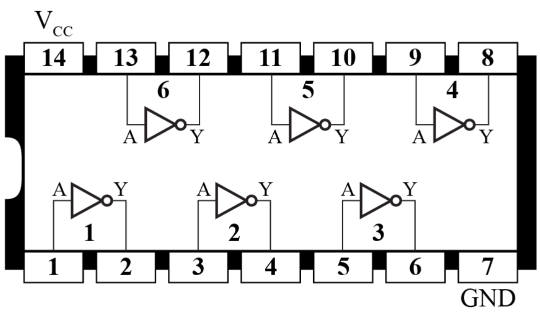

Fig. 3.2. Chip connection diagram in a typical datasheet.

Each datasheet has a connection diagram for the IC, similar to the one shown in **Fig. 3.2**. Note that, depending on the type of IC, the components may be connected in a completely different fashion. The numbering of the DIP IC terminals starts from pin 1 in the bottom left corner and continues *counter-clockwise* around the entire IC. Letters at the beginning of the alphabet, such as A, B, C, denote inputs, while letters at the end of the alphabet: X, Y, Z, denote outputs. Since the NOT gate has only one input and one output, they are labeled as A for the input and Y for the output. In some cases, gate symbols may not be provided and the terminals are labeled as A1, Y1, A2, Y2, etc., where the number indicates the gate number on the IC. Inputs and outputs with the same number belong to the same gate on the IC.

For the IC to function, it must receive power (V_{CC}) and ground (GND) signals that are within the operating range of the IC. This information can also be found in the datasheet. V_{CC} values generally range between 3.3 and 6 V DC, with 5 V considered to be the ideal operating voltage for most ICs used in the laboratory.

The types of integrated circuits used in the laboratory are given in **Table 3.1**. The LS designation on ICs indicates transistor-to-transistor logic (TTL), which is older technology that is slightly slower, more power-hungry, and generally has tighter tolerances regarding the input voltages it accepts. HC, on the other hand, is newer CMOS technology.

Table 3.1. ICs used in the laboratory.

IC part no.	IC Description
74HC00	Quad 2-input NAND gates
74HC02	Quad 2-input NOR gates
74HC04 / 74LS04	Hex inverter
74HC08	Quad 2-input AND gates
74HC32	Quad 2-input OR gates
74HC86	Quad 2-input XOR gate
(7447)	BCD to 7-segment decoder/driver
74590	8-bit binary counters with 3-state output registers
(4511)	BCD to 7-segment latch decoder/driver

Part numbers listed in parentheses ( ) may be substituted based on their availability in the laboratory.

When wiring IC-based circuits, make sure to place the ICs far apart (leave at least 3 holes between neighboring ICs). A good rule of thumb for placing ICs on a breadboard is to place them every 10 holes (e.g., at positions 15, 25, 35, etc.). A sample setup is shown in **Fig. 3.3**.

Note that ICs should always be placed over the middle separator channel of the breadboard. In addition, in this laboratory and in and future designs, use a *four-position DIP switch*, instead of four individual ones, as this will save valuable space on the breadboard. Instructions for using pull-down resistors will be omitted from most wiring diagrams where banks of switches are used.

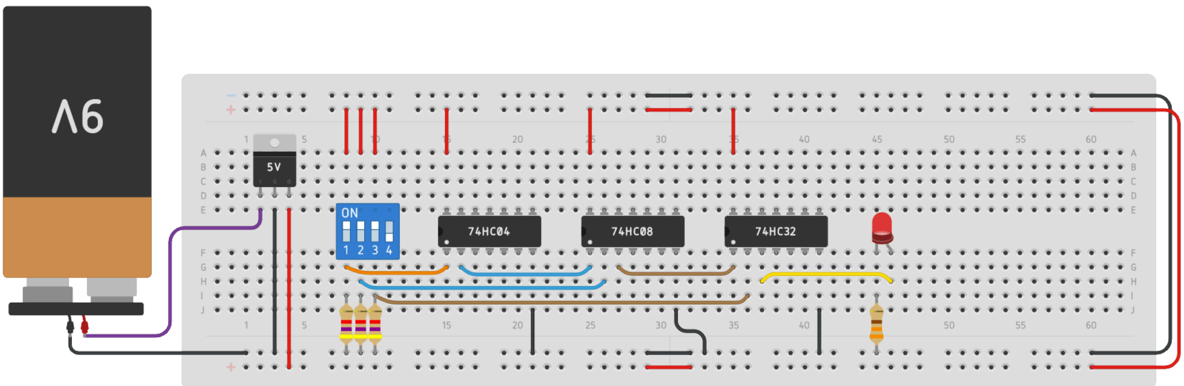

Fig. 3.3. Sample IC-based circuit on a breadboard.

<u>**Important note!**</u> Pay particular attention to making sure the IC is powered (power and ground are connected). This is the most common mistake when wiring complex circuits.

Also, make sure that the power and ground rails are shorted in the top middle and bottom middle sections (and between the top and bottom), otherwise large portions of the breadboard may not receive power, which will lead to erroneous results when testing the circuit.

Voltage Regulators

When using ICs that are sensitive to supply voltage differences, it is a good idea to use a voltage regulator. This device ensures that regardless of the input voltage fluctuation, the circuit will always receive a particular voltage. The most common voltage regulators are designed for a 3.3 V, 5 V, or 12 V DC output.

Since all of the ICs in laboratory are designed to operate at 5 V DC, the LM7805 voltage regulator will be used, shown in **Fig. 3.4**.

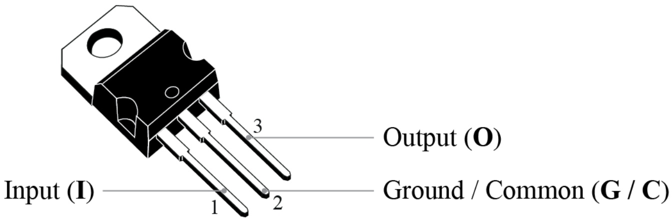

Fig. 3.4. LM7805 voltage regulator pinout.

The input voltage range is 7 to 25 V, while the output voltage will be maintained at 5 V DC. This will allow us to use a standard 9 V battery with the circuit, which was also the case in the sample circuit setup in the previous section.

A suggested wiring layout is shown in **Fig. 3.5**. More information on this voltage regulator can be obtained by searching the internet for its datasheet.

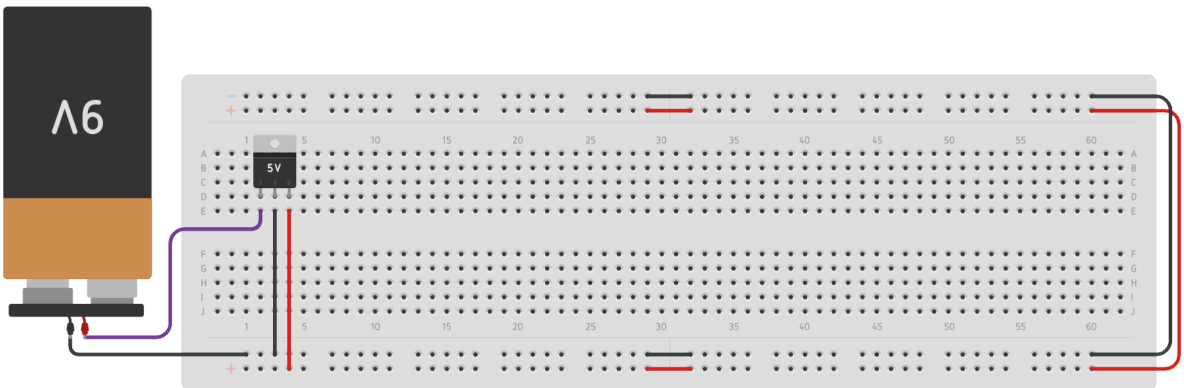

Fig. 3.5. Suggested wiring setup for using a 9 V battery alongside an LM7805 voltage regulator.

Once again, note the wires connecting the left and right sides of the power and ground rails of the breadboard, in addition to the wires connecting the top and bottom rails. This ensures access to power and ground from any position on the breadboard.

4. Laboratory Exercises

Combinational Logic

The relationship between the input(s) and the output(s) can be described by a logic circuit, a truth table, or a waveform. Considering the simple logic circuit presented in **Fig. 4.1**:

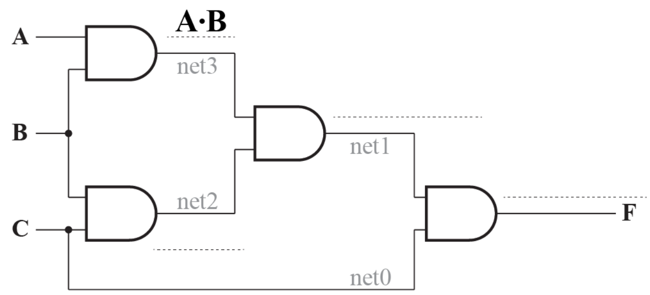

Fig. 4.1. Combinational logic circuit.

1. Label the output of all gates with a Boolean expression.
2. Fill in the intermediate results and outputs in the **Predicted** column of **Table 4.1**.

Table 4.1. Laboratory data table.

Inputs			Predicted					Experimental				
			Intermediate				F	Intermediate				F
A	B	C	net3	net2	net1	net0		net3	net2	net1	net0	
0	0	0										
0	0	1										
0	1	0										
0	1	1										
1	0	0										
1	0	1										
1	1	0										
1	1	1										

3. Draw the output waveform for F, given input values for A, B, and C in **Fig. 4.2**.

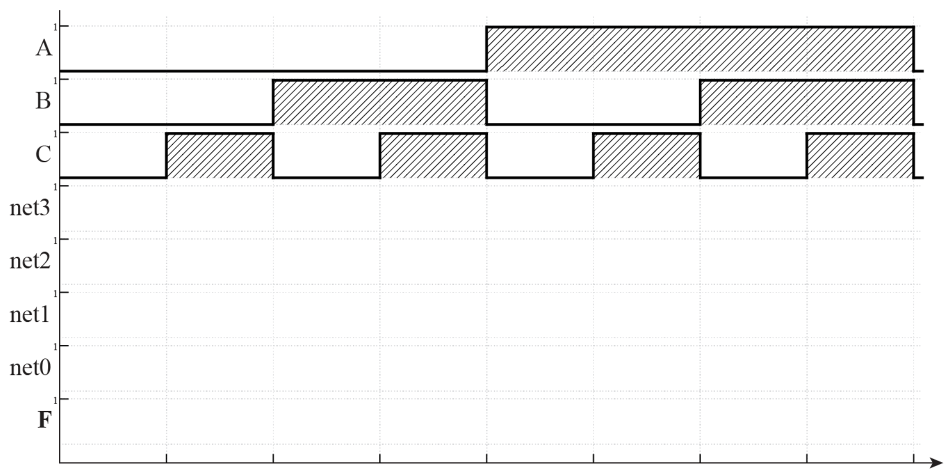

Fig. 4.2. Waveform corresponding to the circuit in **Fig. 4.1**.

4. Build the circuit in **Fig. 4.3**, using the 9 V battery and the LM7805 voltage regulator, as discussed in the Background section of the laboratory and shown in **Fig. 3.5**. Make sure to use the correct IC type (if wired correctly, you should only need a *single* IC in order to implement all of the logic gates in the circuit). To determine locations of gates within the IC, use the 74LS08/74HC08 Quad-AND Gate IC data sheet obtained from a reputable source online. Mark the IC pin numbers that will be used (*e.g.*, 1, 2, 3, 4, etc.) for the gates in the dotted boxes in **Fig. 4.3**. Inputs *A*, *B*, and *C* should connect to the four-position DIP switch with pull-down resistors. Intermediate signals (*nets*), as well as the final output *F*, should connect to LEDs, with which the operation of the circuit can be verified.

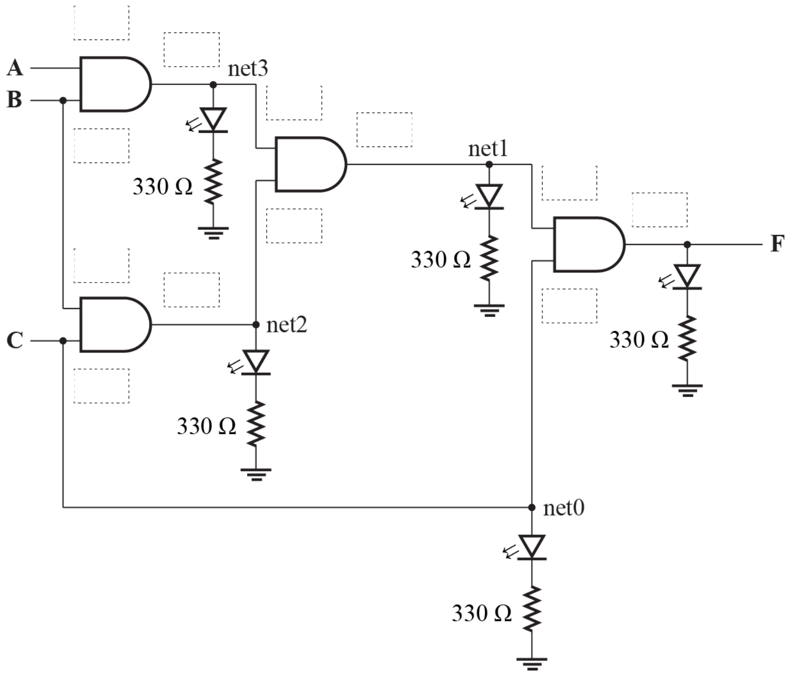

Fig. 4.3. Laboratory circuit.

5. Power the circuit and verify the circuit functionality against the **Predicted** column in **Table 4.1**. Once you are satisfied with the operation of the circuit, fill out the **Experimental** column in the laboratory data table. Note that if there is a mismatch between the Predicted and Experimental columns, likely, your wiring is incorrect.

5. Deliverables

At the conclusion of the laboratory, submit the following deliverables as a single PDF file, using the lab report template posted on the course page:

- Completed **Table 4.1.** Laboratory data table.
- A picture (cropped to just the breadboard and components) of the laboratory setup.
- Signoff working circuitry with the instructor.
- A completed waveform from **Fig. 4.2**.

Provide a detailed answer to the following question(s) as part of the submission:

1. Interpret the output of the circuit. Does the behavior of the output make sense, given the components used? **Explain.**