Lab 7: Digital Electronics, Counters, and Timers

Physics 327

Spring 2025

Goals

Gain experience with digital circuits including logic gates, flip flops, and the 555 timer. Combine digital circuit elements to construct a practical device, a decimal counter. **Note:** This is a two-week lab.

Pre-Laboratory Exercises

To prepare for this laboratory:

1. Read about digital circuits in Part 3 of the textbook (starting on page 149, Faissler).
2. Read about the 555 timer on page 206 in the textbook. Complete Problem 23-4. **Links to most datasheets are included in the Table on Canvas.**

A Logic Gates

Part 1 LED Indicators

For developing digital circuits, LEDs can be useful indicators of the on/off voltage status of a line or of the input/output pin of a device. The digital circuits we will use operate between ground and 5 V, but connecting an LED directly to 5 V will cause enough current to burn it out. Be sure to connect at least a 270 Ω resistor in series with each LED.

Set up a few LEDs of a **10-element LED bar** as shown in Fig. 1 and confirm that they emit light. Keep this circuit set up for testing the logic circuits built later on.

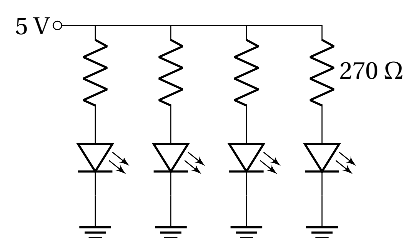


Figure 1: Indicator LED connections.

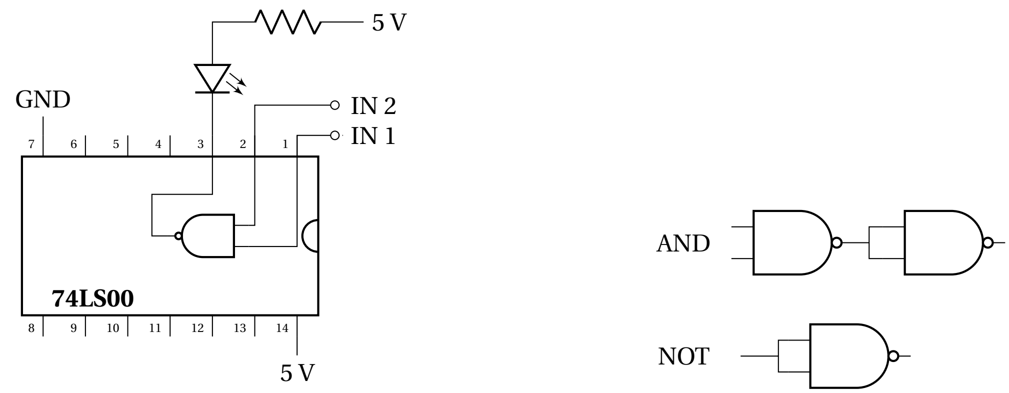
Part 2 74LS00 Quad NAND

The **74LS00** Quad NAND gate contains four independent NAND gates. A data sheet and pin connections for this chip are in Faissler, page 468. Recall that pin 1 is indicated by a small indentation on the chip, and the pin numbering order goes down one side and up the other, such that pin 1 is across from pin 14. ***Important note:* the supply voltage is +5 V (not 12 V).**

First, check that each of the four sections of the chip work as a NAND gate, by hooking the output to the cathode (i.e., the shorter lead) of an LED as shown in Fig. 2a.[1] A TTL logic gate input, when left floating (unconnected), typically behaves as if it were connected to a logic high. This can cause trouble, since you may think an input is high, when in fact it is not connected, so take care with connections to avoid such "floating" inputs.

Set up a NOT with one gate and an AND with another two gates as shown in Fig. 2b. Finally, determine a method to build an OR gate from three NAND gates, and set that up as well. Record the truth table for each case in your report, and check that it is correct. Demonstrate the circuits to your instructor.

[1] The ground side of the LED is used because logic chips generally cannot supply enough current to drive the LED (it might seem to work at first, but is not reliable). Thus, when the LED is on, this means the output is low or false. Be careful when recording results; it can be counter-intuitive to have the LED on for a low state.



(a) 74LS00 quad NAND setup. (b) Logic gate setup.

Figure 2: 74LS00 logic gate configurations.

Question 1: What configuration would you use to construct an OR gate? Include a diagram and the truth table in your report.

B 555 Timer

The **555** Timer is a multi-purpose chip that includes comparators, flip-flop, inverter, transistors that can be used in many different ways, in particular with external RC networks providing a voltage source with a desired time constant. Typical uses for the 555 include a monostable multivibrator (one-shot), astable multivibrator (digital clock), missing pulse detector, and a pulse width modulator. This device is introduced in Faissler pages 206–207, but the best reference is the data sheet starting on page 496, which shows the schematics to perform many different functions. *Important note:* the 555 IC is an 8-pin DIP package, the same as the LM741 op omp; check the print on the chip to ensure you have the correct part. Set up the **555** timer as a clock, as shown in Fig. 3a. Start with C = 1000 pF, R_a = 370 kΩ, and R_b = 470 kΩ.

Describe the characteristics of your output waveform, including its amplitude, in the report. Record or sketch the waveforms on the output and the trigger input (pin 2).

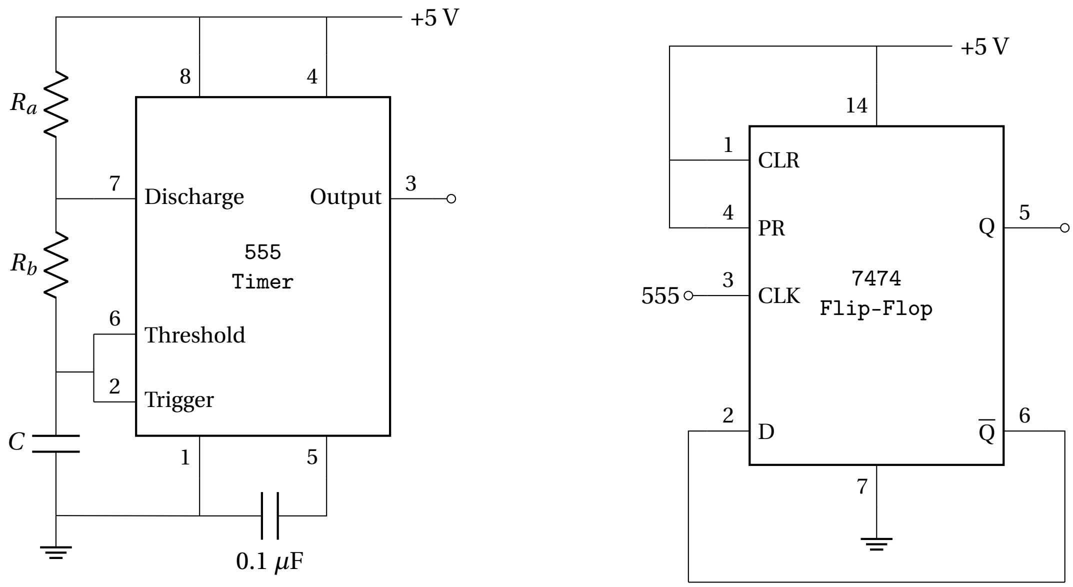
Change C to 1 μF and put one of your LEDs on pin 3. Measure the frequency of the clock (it should be about 1 Hz). Save this circuit for the next section. Note that the 1 μF capacitors in the lab are polarized, i.e. the voltage drop across the capacitor must always be in the direction marked.

Question 2: How do the lengths of the on/off sections compare to the predicted time scales of RC? Does this agree with the analysis in the text in Chapter 23, in the Timer Circuits section?

C 7474 D-type Flip-Flop

A flip-flop is a logic device with two stable states. There are several varieties of flip-flop; here we will use the D-type flip-flop, also known as a “latch.” Our particular IC, the TTL **7474**, adopts the state of the data (D) input when the clock (C) input makes a transition from low to high. There are other inputs — clear (CLR) and preset (PR) — which affect the state of the flip-flop independent of the clock input state. The output (Q) shows the state of the flip-flop, and Q the complement.

The 7474 contains two D-type flip-flops. For the pin configuration, refer to the datasheet. Using one half of a 7474, attach the 555 timer output to the flip-flop clock input, as in Fig. 3b. You should see that the flip-flop acts as a divide-by-two circuit, i.e. outputting a waveform that corresponds to a clock with half the frequency. In doing so, it also makes the pulse symmetric across the low and high states. Repeat this section’s measurements with C = 1000 pF and 1 μF.



(a) 555 timer setup.

(b) 7474 flip-flop setup.

Figure 3: Schematics for Sections B and C.

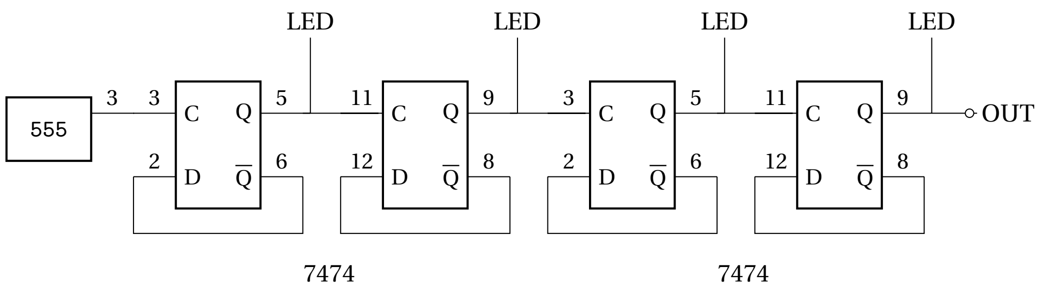


Figure 4: Binary counter setup.

D Binary Counter

Part 1 Counter

Next, by chaining together four flip-flops (in two 7474s) as shown in Fig. 4, construct a divide-by-16 circuit. Note that the power and other connections are not shown in the figure, but must be made for the devices to operate. Remember to connect the $\overline{\mathrm{Q}}$ to D ($2 \rightarrow 6$ and $8 \rightarrow 12$). Putting LEDs on all four Q outputs, you should see that you have a binary counter. Demonstrate this to your instructor and briefly describe the LED patterns in your report.

Part 2 Display

It is much easier to read a number in the familiar *decimal* digits (0–9) than in binary! So, as a final step, a 7–segment LED display unit can be used to display the state of the binary counter, at least in the range from 0 to 9. This unit shows one decimal digit using 7 LED segments to form the numerals 0 through 9; see Fig. 5. A **7448** chip can be used to construct the pattern of segments for each state of the counter's 4 lines (bits) of output. In other words, the 7448 inputs are the 4 lines from the binary counter, and its outputs are the 7 lines showing the state of the segments in the display. The 7448 is a binary-coded decimal (BCD) decoder and only works for counter states between 0000 and 1001, i.e. decimal numbers 0 through 9.

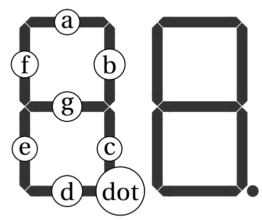


Figure 5: Seven-segment display.

The pin connections of the 7448 are (pins 1–16):

Inputs 1: BCD2, 2: BCD3, 6: BCD4, 7: BCD1

Outputs 9: e, 10: d, 11: c, 12: b, 13: a, 14: g, 15: f

Other 3: NC, 4: NC, 5: NC, 8: GND, 16: +5 V

Here, BCD4 is the slowest line of the binary counter to change, and BCD1 is the fastest. NC means no connection. Pins are numbered counter-clockwise from top left of the 16-pin chip. Connect the BCD pins to the $\overline{\mathrm{Q}}$ pins of the 7474 units. Display segments are labeled a through f, as shown in Fig. 5.

Question 3: Why is $\overline{\mathrm{Q}}$ used rather than Q, as in the previous section?

The pin connections of the common-cathode 7-segment dual digit display are (pin 1 is a bottom left, pins run counter-clockwise):

- Left decimal digit (pins 1-4; 14-18): 1: e, 2: d, 3: c, 4: dot, 14: GND, 15: b, 16: a, 17: g, 18: f.
- Right decimal digit (pins 5-9; 10-13): 5: e, 6: d, 7: g, 8: c, 9: dot, 10: b, 11: a, 12: f, 13: GND.

Connect the display to the 7448 outputs accordingly, using a 270 Ω resistor between ground and the GND pins of the display. Report how the 7448 reacts to the counter states between 1010 and 1111 as the binary counter advances through the complete range. Does the display count upwards 0 to 9, or downwards 9 to 0?