Lab 9: Wheel circuit

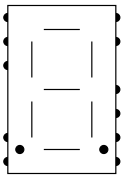
Lab note: *You* must *find a lab partner for this lab. You will not submit a lab report; instead, the instructor will check you off once you have completed and tested your circuit.*

Objectives

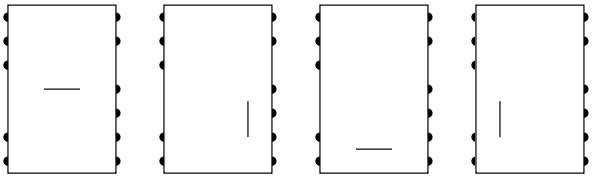
- to experience building physical circuits using a breadboard.
- to practice developing sequential circuits.

A Goal

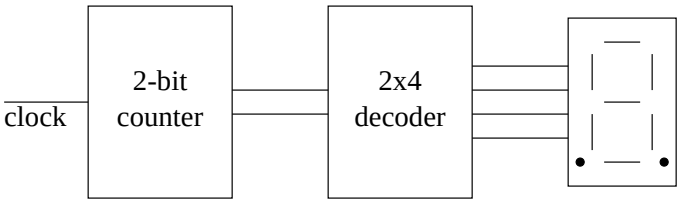
In this lab, we will build a circuit on a breadboard, using a kit of chips and wires. Among the chips will be a seven-segment display for digits.



The job of our circuit will be rotate a lighted segment clockwise around the lower loop. In other words, the seven-segment display should cycle through the following sequence repeatedly.



To accomplish this, we'll connect a two-bit counter to a 2×4 decoder, which is itself connected to a seven-segment display.



This would be easy if our kit included a two-bit counter and a 2×4 decoder. But, besides the seven-segment display, the only useful elements that the kit provides are simple logic gate chips (NAND, NOR, NOT, AND, NAND, OR, and XOR) and JK flip-flops.

B Preparation

Before beginning to build the circuit, we'll need to design the circuit. The design process will be in three parts: First, we'll design the 2×4 decoder, then we'll design the two-bit counter, and then we'll put them together.

B.1 2×4 decoder

The 2×4 decoder has two inputs i_1 and i_0 and four outputs o_3, o_2, o_1, and o_0. At any time, one output will be 0 and the rest will be 1.[1] We can regard the input as a two-bit number, and this number is the index of the output that should be 0.

i_1	i_0	o_3	o_2	o_1	o_0
0	0	0	1	1	1
0	1	1	0	1	1
1	0	1	1	0	1
1	1	1	1	1	0

Design a 2×4 decoder and draw a circuit incorporating these. Since we will have NOR and NAND gates in our kit, feel free to use them in your circuit. You want to use as few gates as possible, to make building the circuit easy.

B.2 Two-bit counter

The two-bit counter takes a "clock" as an input and has two outputs. Each clock pulse, the two-bit number produced by the counter should go up by 1, cycling back to 0 after it reaches 3.

Using the design procedure outlined in class, design a two-bit counter using two JK flip-flops remembering Q_1 and Q_0. (If you take greatest advantage of the don't-cares that appear in the design process, you'll find that they're not necessary. This will make your circuit-building easier.)

B.3 Putting it together

Now that you have your two-bit counter and 2×4 decoder, draw a complete circuit incorporating the JK flip-flops. Bring this to the lab, so that you're ready to wire the circuit together.

Note that each JK flip-flop outputs both Q and $\overline{Q}$. You should take advantage of this in your circuit, as it will mean that your circuit will involve fewer wires (making it easier for you in the long run).

C Wiring the circuit

Electronic components, being hardware, can often result in unreliable behavior. For this reason, I strongly suggest that you divide your work in this lab into three parts, testing your circuit thoroughly after each part. You are invited to get an instructor or TA to confirm that your circuit works properly for each part.

Your kit will include the following chips.

74LS00	NAND gates (quad 2-in)
74LS02	NOR gates (quad 2-in)
74LS04	NOT gates (hex)
74LS08	AND gates (quad 2-in)
74LS10	NAND gates (triple 3-in)
74LS20	NAND gates (dual 4-in)
74LS32	OR gates (quad 2-in)
74LS47	BCD-to-7 seg decoder/driver
74LS76	JK flip-flop (dual)
74LS76	JK flip-flop (dual)
74LS86	XOR gate (dual 2-in)
74LS153	2×4 multiplexer (dual)

[1] This is the inverse of a regular decoder, which has one output 1 and the rest 0 at any time.

C.1 Two-bit counter

Build the two-bit counter first.

When you place chips into the breadboard, it's important that they be oriented correctly. Each chip includes notch; this should go up, and pin 1 will be at the upper left-hand corner. Many chips include an additional dimple next to pin 1, also for orientation purposes.

The JK flip-flop chip includes five inputs for each flip-flop and two outputs, so that each flip-flop uses 7 pins. The chip includes two flip-flops, for a total of 14 pins, plus two more pins, labeled V_{CC} and GND.

We will find that every chip has these pins labeled V_{CC} and GND. The V_{CC} pin should be connected to positive voltage, which on the breadboard means connecting it to one of the vertical columns prewired to the top with red wire. The GND pin should be connected to negative voltage, which on the breadboard means connecting it to one of the vertical columns prewired to the top with a black wire.

WARNING: *Do **not** connect any wires to the middle two rows at the top of the breadboard. These middle rows are connected to a 15-volt supply, and the chips can handle only 5 volts. The higher voltage will burn the chip, resulting in a foul smell, a damaged breadboard and chip, and possible injuries.*

Of the 5 input pins to the JK flip-flops, the PR and CLR pins should be connected to positive voltage, and the CK pin should be connected to the clock on the far left side of the breadboard (in the region labeled "function generator"). Your J and K inputs will come from the circuit you designed.

In the function generator, ensure that the upper left switch is set to Hz (KHz will be too fast for the circuit), and ensure that the lower switch is set to the far right setting (the square wave output). The two sliders should be at their middle setting. The upper right switch is best set to 10; 1 will make the clock run slower and 100 will make it faster.

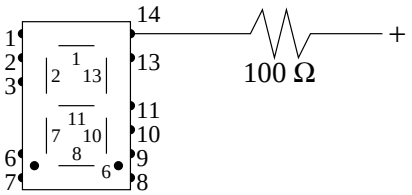
For testing purposes, connect the Q outputs of the two flip-flops to the LEDs on the far right side of the breadboard (labeled "logic indicators"). When the breadboard is turned on, the LEDs should demonstrate that the counter is repeatedly counting from 0 to 3.

C.2 2×4 decoder

Now build your 2×4 decoder, attached to the 2-bit counter. You should test this circuit, by attaching its outputs to the LEDs and ensuring that they cycle through the pattern. You should find that three of the four lights will always be on, with the light that is off cycling among the four.

C.3 Seven-segment display

Finally, we will attach our seven-segment display to the circuit. The input pins correspond to the display segments as follows.



Note that the segments work the opposite of how you would expect: As long as you have positive voltage going into a pin, the corresponding segment will be *off*. This is why we built our decoder to do the inverse of its normal behavior.

Pin 14 of the seven-segment should be connected via a 100Ω resistor to positive voltage. A resistor should be in your kit. The seven-segment display does not need to be connected to ground.

When you complete and test your circuit, show it to your instructor, who will check you off as completing the laboratory. There is no lab report to produce.