Physics 4700 Experiment 7
Digital Circuits

Almost all of the circuits in this part of the course will be built using the “DIGI DESIGNER” and tested using a logic probe. You should become familiar with both of these tools before you start the lab. The bookshelf contains bounded copies of spec sheets for the chips used in this lab.

1) Verify the truth table for a NAND gate (7400 chip), NOR gate (7402), AND gate (7408), OR gate (7432) and Exclusive OR gate (7486). Use the lamp switches on the DIGI DESIGNER to signal a high or low state. What is the output voltage of a high or low state from the above gates?

2) A small company has 100 shares of stock divided among 4 people. Each share entitles its owner to a vote. The shares are divided as follows:

Mr. A 10 shares
Ms. B 20 shares
Mr. C 30 shares
Ms. D 40 shares

A measure that has been voted on passes if there is a two thirds majority. Each person votes with all of their shares (1) or none of their shares (0). Write out the truth table for all possible votes. Construct the logic equation for the votes and use Boolean algebra to simplify the equation. Design a circuit using logic gates which lights a lamp whenever a measure passes. Hint: To simply your equation, you might wish to use C = C + C, i.e. ABCD = ABCD + ABCD.

3) Verify the truth table for the JK flip-flop (74S112) including the preset and clear options. Note: a low PRESET or CLEAR has higher priority over the J and K inputs, i.e. the PRESET or CLEAR (low) command will get executed regardless of the J or K inputs and hence the J and K inputs should be used when PRESET and CLEAR are both high.

4) Using 3 JKFF's build a circuit that counts from zero to seven, i.e. 0,1,2,3,4,5,6,7,0,1... After you have verified that the above circuit works using the LED lights on the DIGI DESIGNER, hook up the LED display (see Appendix) to your circuit and verify that the circuit counts from zero to seven.

5) Add components to the circuit in Part 4 such that it now counts from zero to nine. You will have to use the reset on the flip-flops.

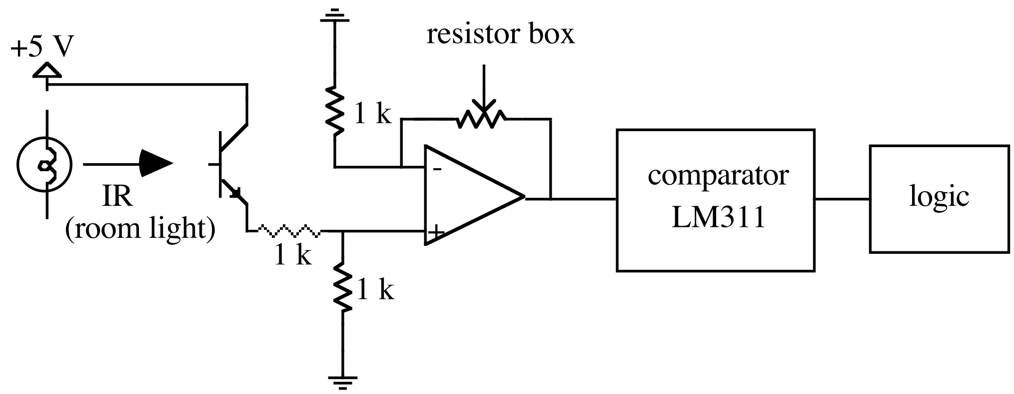
<u>Do Part 6A or Part 6B</u>

6A) Build a DC analog to digital voltmeter (similar to the problem in Homework VII). This circuit will display on the LED:

0 if $V_{in} < 1$ Volt
1 if $1 < V_{in} < 2$ Volts
2 if $2 < V_{in} < 3$ Volts
3 if $V_{in} > 3$ Volts

For comparators use LM311's. The use of the LM311 is outlined below. Finally, hook up a flip-flop so that by pressing a button you can either latch the LED and have the display remain fixed when the input is removed from the circuit or clear the display.

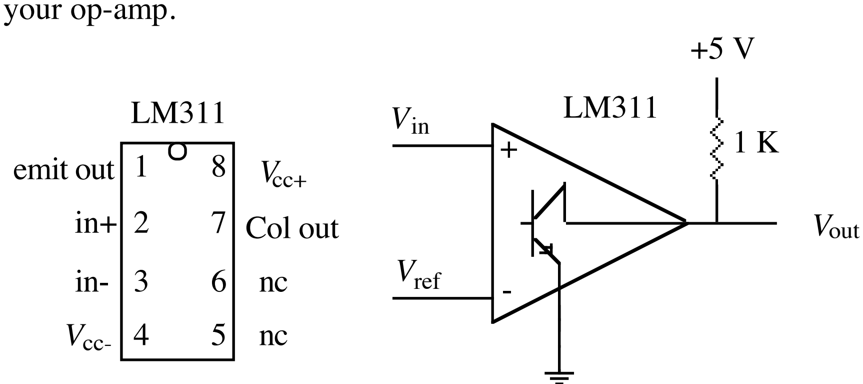
6B) Build the infrared (IR) burglar detector shown below. The room lights are used as a source of IR radiation. The IR light is received by a photodiode receiver sensitive to IR light. A burglar is detected when the IR beam is interrupted. The photodiode (see diagram below) acts like a transistor where the base current is replaced by a photoelectric current proportional to the input light. The photodiode thus has an emitter current proportional to the input light. The op amp converts this current into a voltage. A resistor box is used to set the sensitivity of the circuit's light collection.

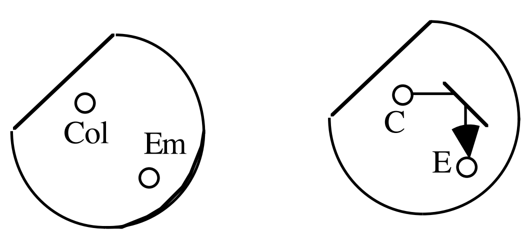


A comparator is used to turn the op amp's voltage into a digital pulse. For a comparator use an LM311 (see below for details on this device). The comparator should "fire" (give 0 V) when the IR beam is interrupted. Finally, design and hook up a flip-flop so that if the beam is interrupted a display diode remains lighted, indicating an intruder has broken into your house and disturbed the IR beam. The flip-flop circuit should contain a reset so that you can clear the alarm.

<u>LM311 Comparator</u>

Connect the LM311 up as outlined in the figure below. Use +5 V for V_{cc+} and -5 V for V_{cc-}. If the positive (+) input terminal of the LM311 is at a higher voltage than the negative (-) input, the output will be 5 V, otherwise the output will be zero Volt. The 1 kΩ resistor (external to the chip) is called a "pull-up" resistor. For the burglar detector V_{ref} must be determined by looking at the output of your op-amp.

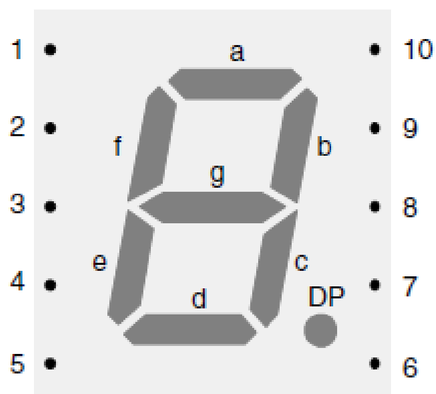




Infrared Photodetector

Appendix 1: Use of the 7-Segment LED Display

The 7-segment display is familiar from its use in consumer products through the years. In this lab, we'll use an LED version. Each of the segments is actually a separate light-emitting diode. There is also a decimal point, which will not be used in this lab. Each segment has its own anode, but all the cathodes are connected together. This is called the "common cathode" configuration. Common anode configurations are also widely used but are probably less intuitive to hook up. For our display, the cathode will always be connected to ground. To make a segment light up, its anode must be connected to a logical TRUE or HIGH. To turn off a segment, its anode must be connected to a logical FALSE or LOW. The pin assignments are shown in Figure 1.



Pin	Connected to…
1	Segment **g** anode
2	Segment **f** anode
3	Cathode
4	Segment **e** anode
5	Segment **d** anode
6	Decimal Point
7	Segment **c** anode
8	Cathode
9	Segment **b** anode
10	Segment **a** anode

Figure 1. Pin assignments of the TDSG3160-M 7-segment LED display. Note that there are two cathode pins (3, 8) but only one needs to be connected to ground. The other should be left unconnected. Also, pin 6 should be connected to ground since we won't be using the decimal point. Taken from Vishay website.

You may well imagine that developing the logic to control the 7-segment display is time consuming. For example, if you had a binary coded decimal "0100", representing the number 4, you would want to illuminate segments f, g, b, and c. If you had "0011", representing the number 3, you would illuminate a, b, g, c, and d. Fortunately, there are chips with the logic to take care of this for you. In this class you'll use the CD74HCT4511E chip, (known as 4511 for short). This is a CMOS chip, but the "T" in the name indicates it accepts TTL inputs. The pin assignments are shown in Figure 2 and the truth table in Figure 3.

For the BCD inputs, D0 is the least significant bit and D3 is the most significant bit. The 4511 is not a hexadecimal display driver. If your BCD value exceeds "1001", which is 9, the display will just be blank.

The other three inputs are as follows:

$\overline{LT}$ is lamp test. Setting this pin to LOW or FALSE will illuminate all the segments, regardless of the state of the other inputs. This is a quick way to make sure the display is working.

$\overline{BL}$ is blanking. Setting this pin to LOW or FALSE will turn off all the segments, regardless of the states of D0 – D3. Notice from the truth table that LT takes priority over BL.

$\overline{LE}$ is latch enable. When this pin is HIGH, it enables the latches to store the BCD inputs. If you change D0 – D3, the display should retain the previous character. When this pin is LOW, if you change D0 – D3 the display should instantly change to the new character.

The "bar" over the function name indicates active low or negative logic. (Although by this convention it would seem that "latch enable" should not have a bar over it).

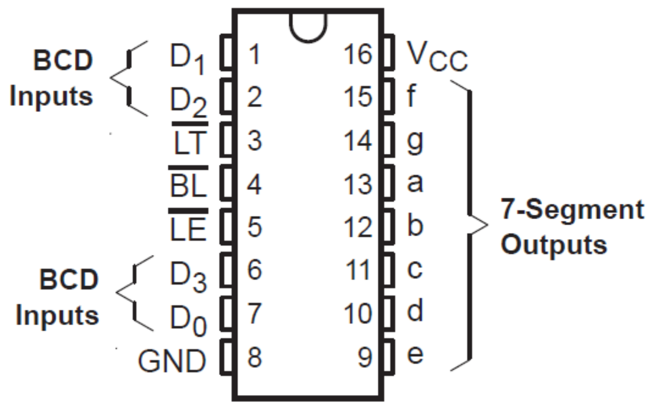


Figure 2. Pin assignments of the CD74HCT4511E controller chip for 7-segment display. Taken from Texas Instruments website.

Finally, when using LEDs, it's very important to limit the current going through them so they don't burn up. According to the data sheet for your 7-segment display, the absolute maximum current per segment is 20 mA. To be on the safe side, we'll assume a typical current of 15 mA. Then assuming a voltage of 5 V is applied, by Ohm's Law we would need a resistor with R = 333 Ω. Picking the next largest available resistor, you would use 350 Ω or 360 Ω, which is provided in your kit. Each resistor should be placed between the output of the 4511 and the appropriate pin of the 7-segment display.

FUNCTION TABLE

INPUTS							OUTPUTS							
$\overline{LE}$	$\overline{BL}$	$\overline{LT}$	D_3	D_2	D_1	D_0	a	b	c	d	e	f	g	DISPLAY
X	X	L	X	X	X	X	H	H	H	H	H	H	H	8
X	L	H	X	X	X	X	L	L	L	L	L	L	L	Blank
L	H	H	L	L	L	L	H	H	H	H	H	H	L	0
L	H	H	L	L	L	H	L	H	H	L	L	L	L	1
L	H	H	L	L	H	L	H	H	L	H	H	L	H	2
L	H	H	L	L	H	H	H	H	H	H	L	L	H	3
L	H	H	L	H	L	L	L	H	H	L	L	H	H	4
L	H	H	L	H	L	H	H	L	H	H	L	H	H	5
L	H	H	L	H	H	L	L	L	H	H	H	H	H	6
L	H	H	L	H	H	H	H	H	H	L	L	L	L	7
L	H	H	H	L	L	L	H	H	H	H	H	H	H	8
L	H	H	H	L	L	H	H	H	H	L	L	H	H	9
L	H	H	H	L	H	L	L	L	L	L	L	L	L	Blank
L	H	H	H	L	H	H	L	L	L	L	L	L	L	Blank
L	H	H	H	H	L	L	L	L	L	L	L	L	L	Blank
L	H	H	H	H	L	H	L	L	L	L	L	L	L	Blank
L	H	H	H	H	H	L	L	L	L	L	L	L	L	Blank
L	H	H	H	H	H	H	L	L	L	L	L	L	L	Blank
H	H	H	X	X	X	X	†	†	†	†	†	†	†	†

X = Don't care

† Depends on BCD code previously applied when $\overline{LE}$ = L

NOTE: Display is blank for all illegal input codes (BCD > HLLH).

Figure 3. Truth table for the CD74HCT4511E. Taken from Texas Instruments website.