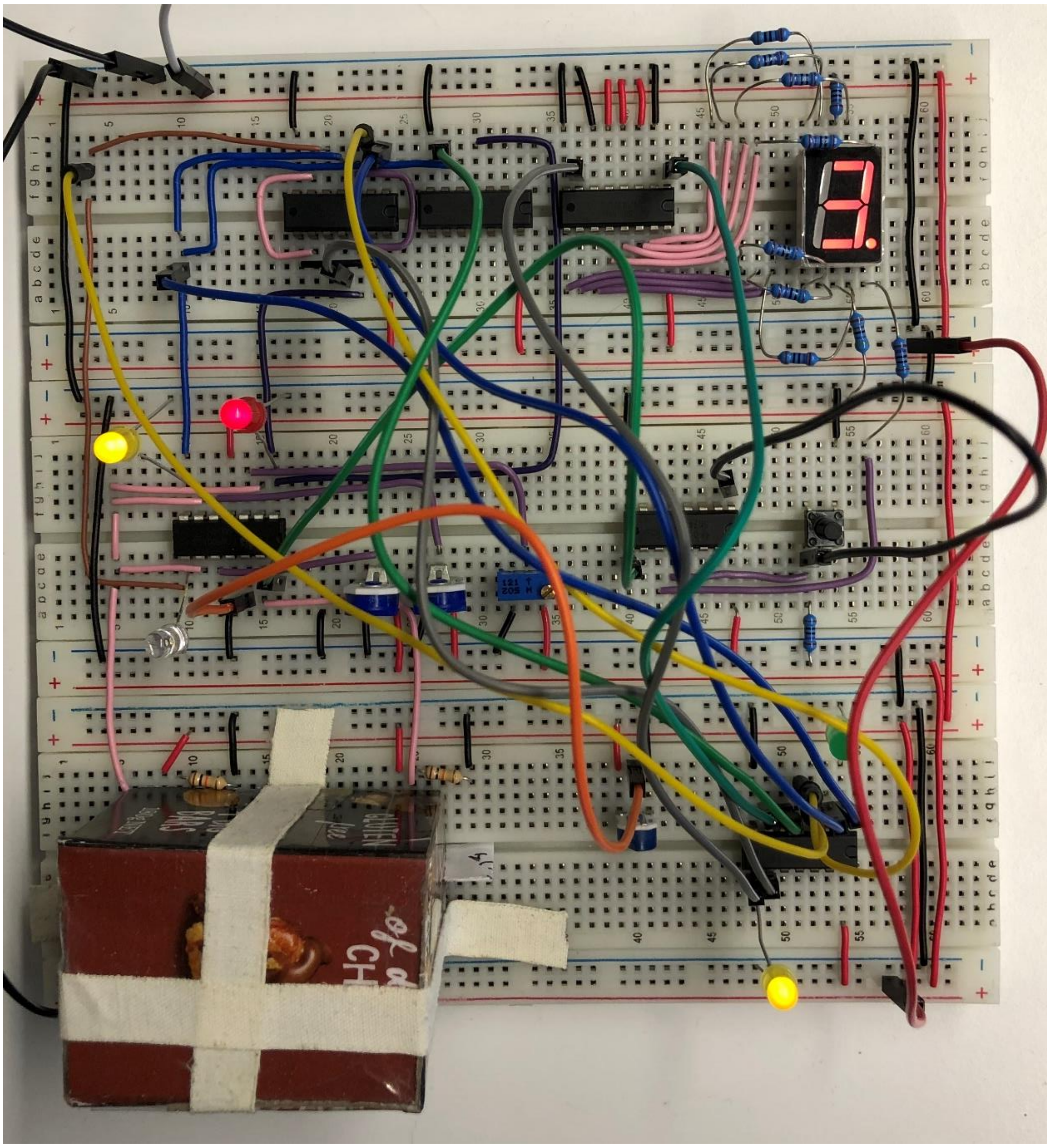
MTRX 1705 Assignment 2

Opamp Circuit: Paper jam detector



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Requirements definition

The assignment is aimed to build up an electronic circuit that demonstrates how paper detectors work in a printer. Once the paper is detected between the sensor, the number of sheets of paper will be displayed on the 7-segment LED (either 0, 1, 2 or 3). If two or three sheets of paper pass through the sensor at the same time, the decimal point LED will be turned on which is defined as the jammed state. The user needs to push the reset button, otherwise the decimal will not disappear.

System design

There are four modules throughout the circuit.

1. **Detectors**
   - Detector1 is used to detect the number of sheets of paper.
   - Detector2 is used to ensure that the decimal point lights up when there are more than 1 paper.

   The LDR is parallel to the LED and in series with a fixed 10kΩ resistor.
   Different number of sheets of paper inserted will affect voltage to change.
   The output of voltage divider is the three V^- inputs of op amp.

2. **Opamp**
   LM324 quad op amp is used to condition the input signal from the two LDRs supplied.
   V^+ input:
   - V_{out} from trimpots. (three trimpots in series connecting from VCC to GND).
   - Individual V_{out} from trimpot to control the voltage when more than one sheet.

   V^- input: V_{out} from LDR1 or LDR2.
   Output: 3 Binary outputs (Q_0, Q_1, Q_2) and a clock signal to the D flip-flop.

3. **Output Logic**
   According to the BCD of 74LS47 decoder, simplify the logic circuit by using two NAND gates and one NOT gate. Each segment of 7-seg display has their own resistors (270Ω).
   Input: A and B.
   Output: Corresponding segment pin.

4. **State memory**
   D Flip-Flop is used to store the jammed state and only changes when it is triggered by pressing the button.
   Inputs: D, CLK signal and CLR.
   Outputs: Q’ connecting to the pin dp on 7-segment display.

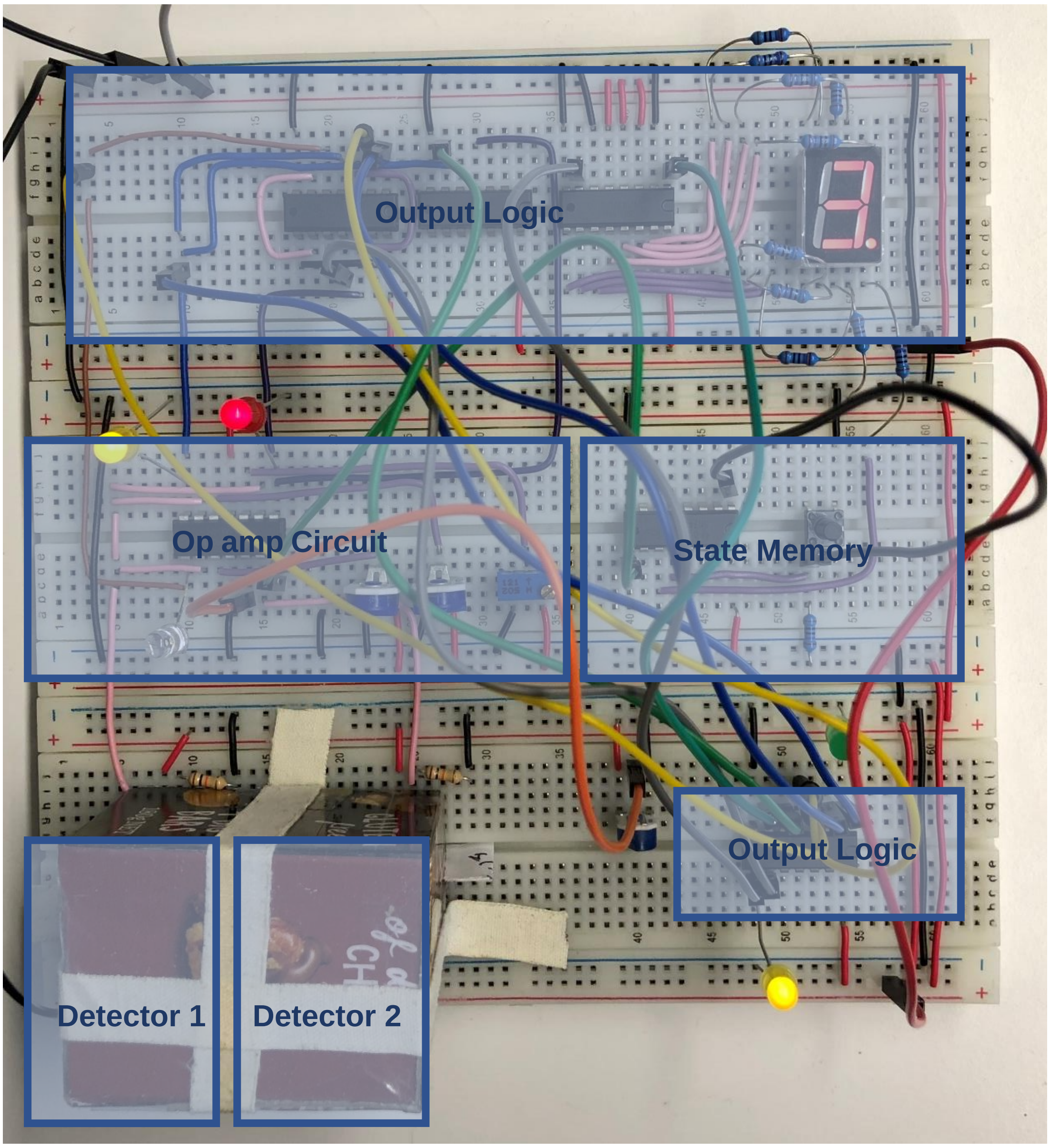


Figure 1 Structure distribution on the breadboard

Detailed design

3.1 Design definition

Define the states

	State	Q_0	Q_1	Q_2
0 sheet	A	0	0	0
1 sheet	B	1	0	0
2 sheets	C	1	1	0
3 sheets	D	1	1	1

Table 2 State names

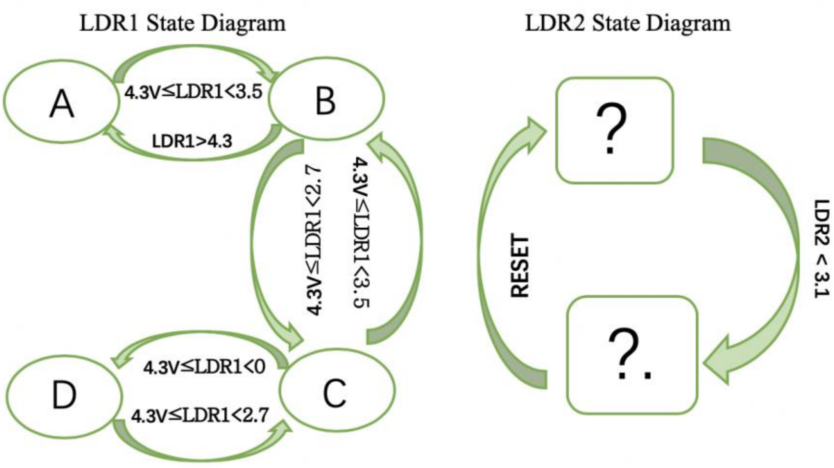
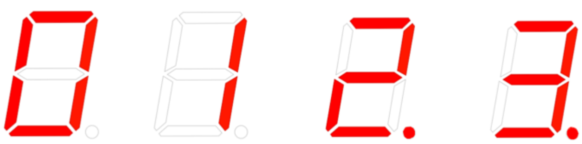


Figure 4 States change diagram ('?' means any numbers)

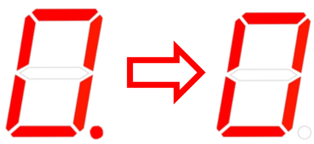
Define the outputs

Display corresponding number of papers without order.



0 sheet 1 sheet 2 sheets 3 sheets

The decimal point LED will turn off when press the button.



3.2 Detector 1 & 2

photosensitive resistors

	LDR 1 Voltage (V)	LDR 2 Voltage (V)
0 sheet	4.5	4.62
1 sheet	4	4
2 sheets	3.1	3.1
3 sheets	2.4	2.8

Table 1 Voltages in 4 cases

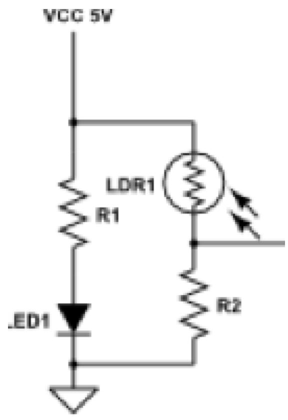


Figure 2 Detector1

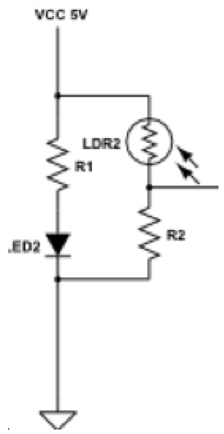


Figure 3 Detector2

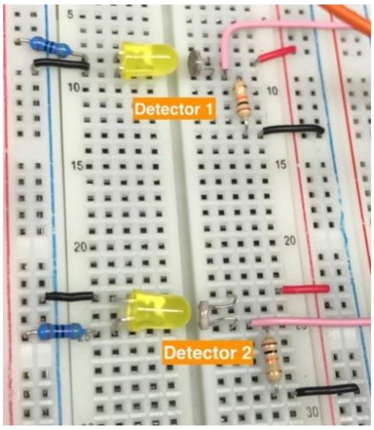


Figure 4 Detector on the breadboard

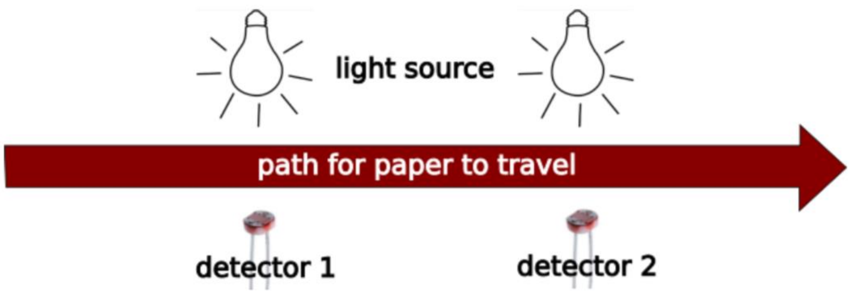
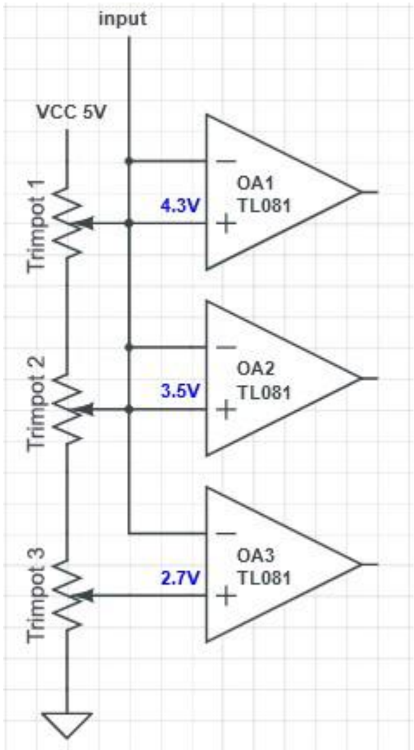


Figure 5 Paper Detector Layout

Designing a circuit for Detector1, the LDR is parallel to the LED and in series with a fixed resistor to make a voltage divider that can provide a good range of voltage. The circuit of Detector2 is the same to the Detector1. Enclosing the sensor in the cardboard to control the light source. The resistance of LDR will change due to the lightness.

3.3 Op amp Circuit

Three trimpots are used to set up reference voltages according to Table1.



Input Voltage	Output 1	Output 2	Output 3
>4.3V	0V	0V	0V
<4.3V >3.5V	5V	0V	0V
<3.5V >2.7V	5V	5V	0V
<2.7V	5V	5V	5V

Figure 6 Op amp

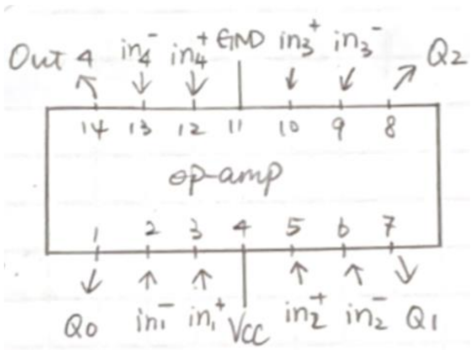


Figure 7 Op amp inputs/outputs

The change of input voltage depends on the numbers of pieces of paper that have fed through the Detector1. Different voltages will go through Op amp and generate different outputs (Q0, Q1, Q2).

3.4 Output Logic

The 74LS47 decoder is used to decode the BCD to drive a 7-segment display LED. Since four numbers will be displayed, only two inputs are needed which are input pin A & B, thus connecting unnecessary input pin C & D to the ground. According to the BCD, to set out the truth table for decoding and simplifying the program.

Truth Table for Decoding

State	Q_0	Q_1	Q_2	B	A
A	0	0	0	0	0
B	1	0	0	0	1
C	1	1	0	1	0
D	1	1	1	1	1

Table 3 Decoding

Solve for A

Q_0Q_1 / Q_2	00	10	01	11
0	0	1	X	0
1	X	X	X	1

Table 4 K-map for output A

$$\mathbf{A} = Q_0 Q_1'Q_2' + Q_0Q_1Q_2$$
$$= Q_0 (Q_1'Q_2' + Q_1Q_2)$$
$$= (Q_0 \cdot ((Q_1' \cdot Q_2')' \cdot (Q_1 \cdot Q_2)')')'$$

Solve for B

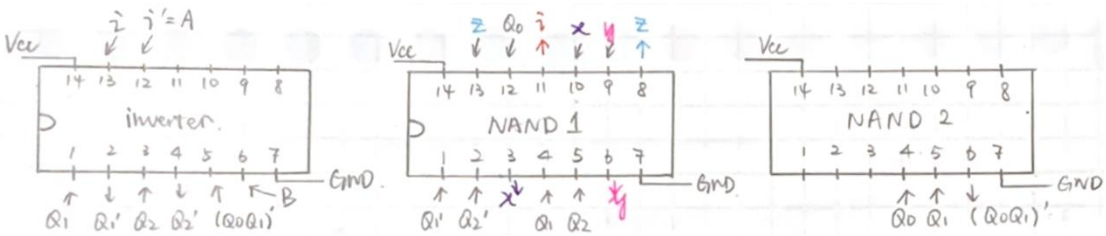
Q_0Q_1 / Q_2	00	10	01	11
0	0	0	X	1
1	X	X	X	1

Table 5 K-map for output B

$$\mathbf{B} = Q_0Q_1Q_2' + Q_0Q_1Q_2$$
$$= Q_0Q_1 (Q_2' + Q_2)$$
$$= Q_0Q_1$$
$$= (Q_0 \cdot Q_1)'$$

Using two NAND gates and one NOT gate to solve out output A and B.

Detailed graph of logic gates



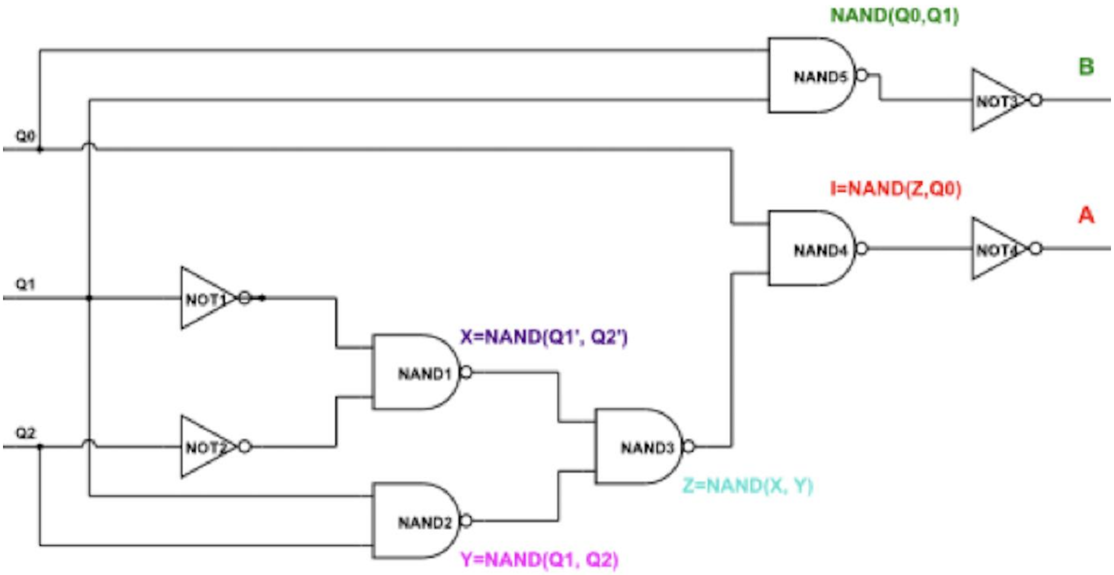


Figure 8 Logic circuit

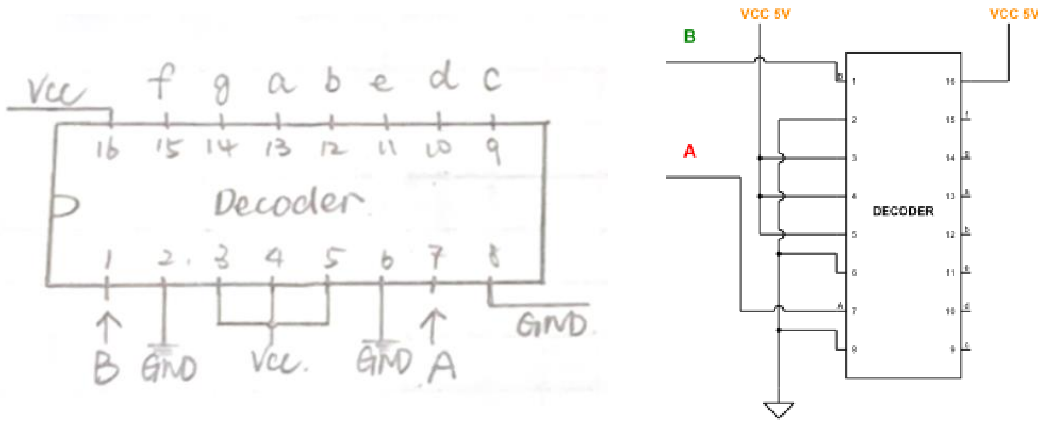


Figure 9 74LS47 Decoder

For the 74LS47 to decode properly and work well with the 7-segment display LED, the pins LT, BI/RBO and RBI must be connected to the voltage resource. Connect corresponding output letter to the 7 segments with proper resistors (270Ω).

3.5 State memory

The state machine is used to define whether the paper is jammed or not. It will transition between states when the paper is detected by Detector2. Once the V^{+}in is less than 3.1V (more than one paper is fed through the Detector1), the paper will be jammed.

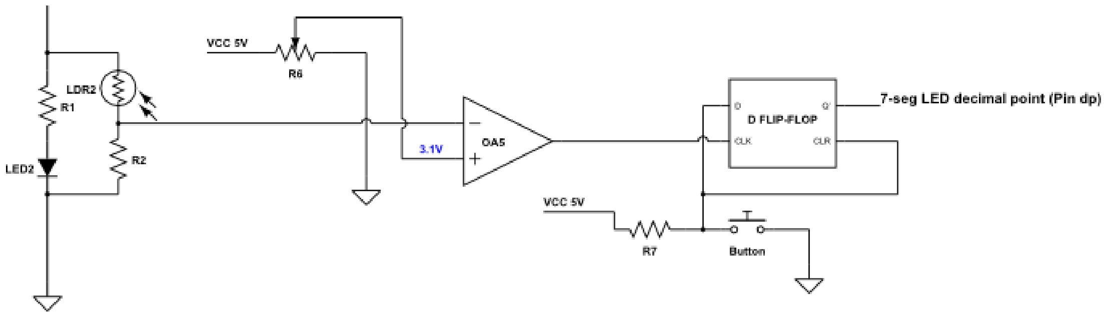


Figure 10 State Machine

Using op amp to condition the input signal from the LDR supplied, then the output will generate the clock signal on low to high. The flip-flop stores the jammed state of input D (HIGH), causing output Q' (LOW) and the 7-segment decimal point LED turns on. Take the Clear pin connect to the ground once press the button, in order to reset the flip-flop and turn off the decimal point LED.

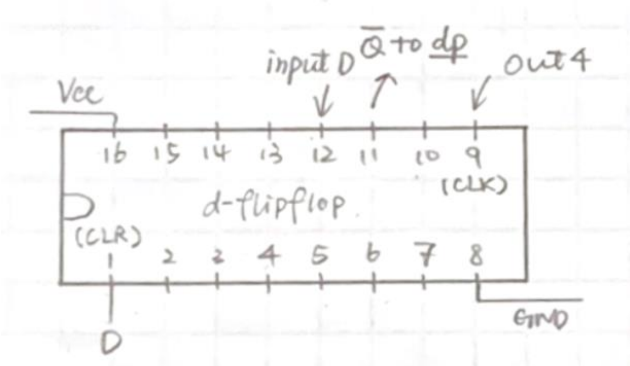


Figure 11 D Flip-flop

3.6 Diagram for the whole system

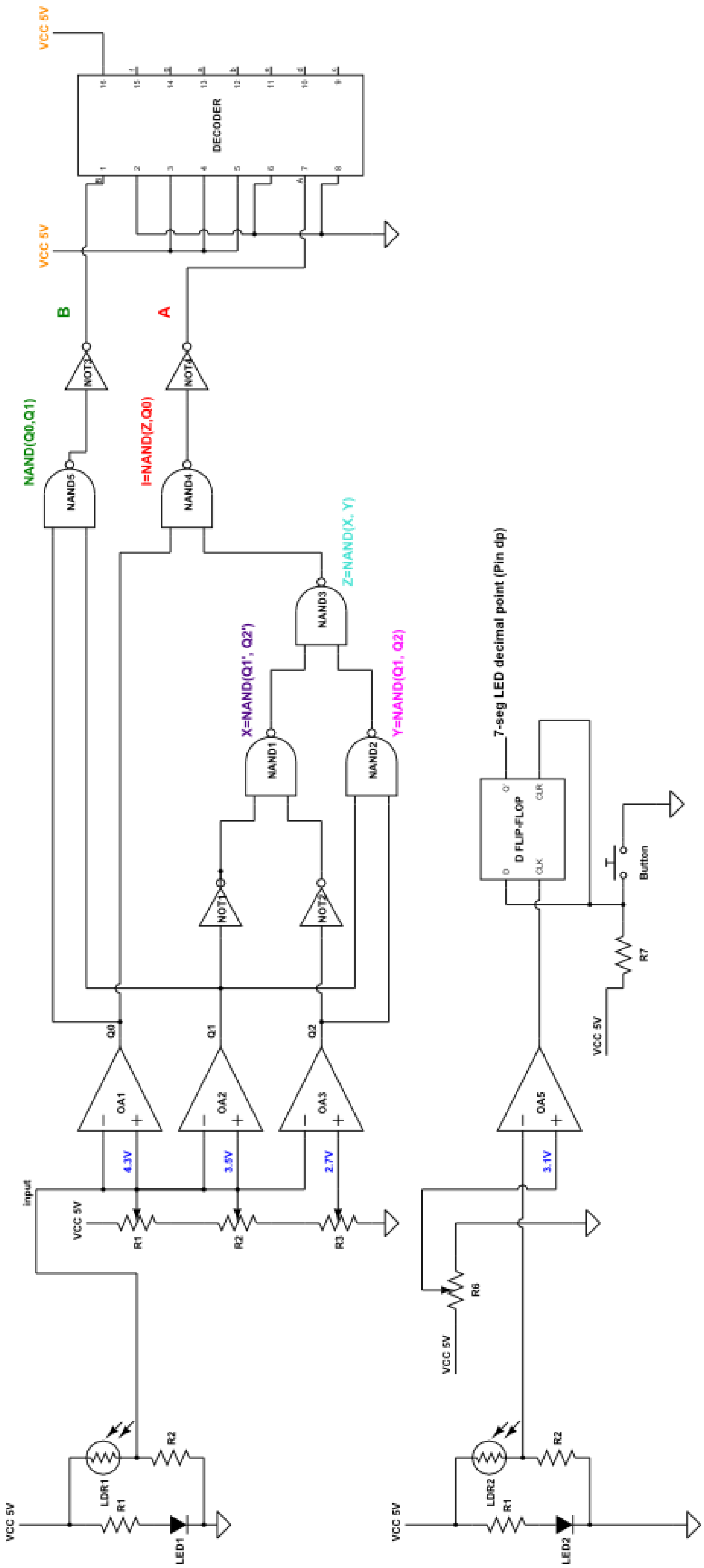


Figure 12 The whole system circuit

Detailed testing

Test points: Outputs of the op amp and D Flip-Flop.

define 0~0.8 V as Low Voltage and 2~5 V as high

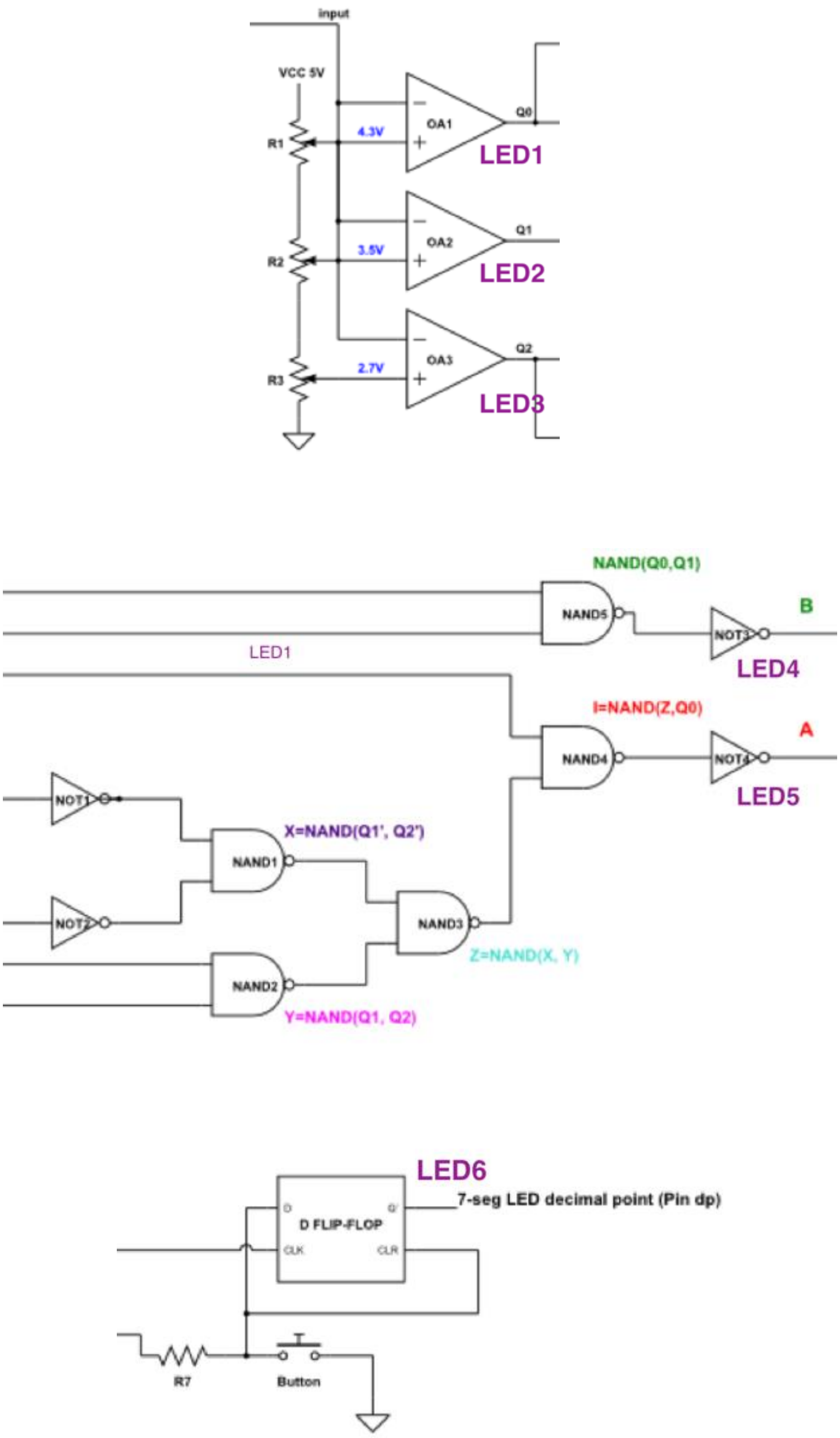
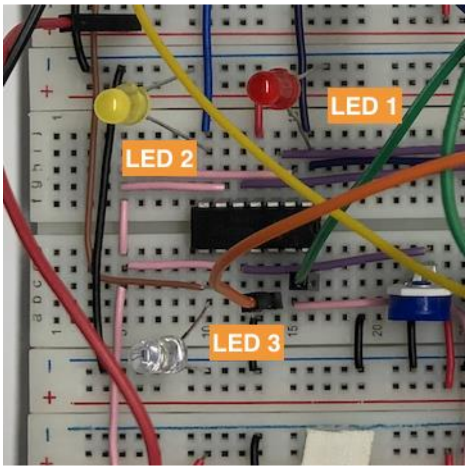


Figure 13 LED test positions

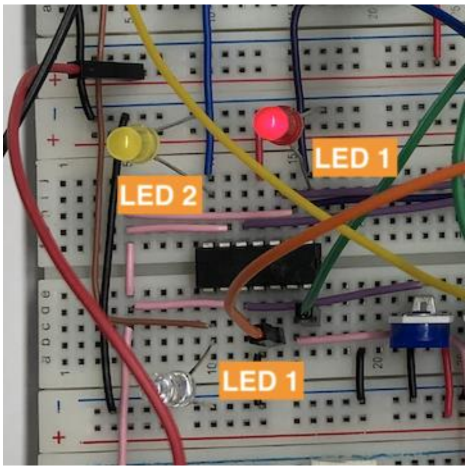
Testing op amp outputs

Test points: Three outputs of op amp.

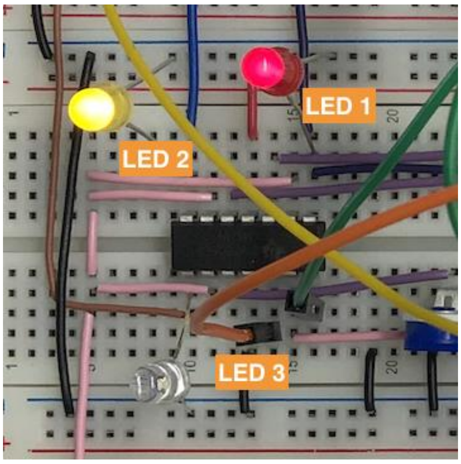
- Attach three LEDs to op amp outputs (Q_0, Q_1, Q_2)
- Connect the positive pole of LED to the outputs and connect the negative pole to ground
- High output signal == LED turns on
- Low output signal == LED turns off
- Compare corresponding performance to the truth table



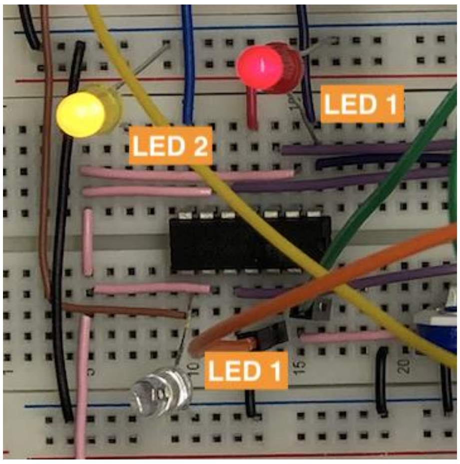
At 'State A', three outputs are LOW, thus no LED light up.



At 'State B', Output Q_0 is HIGH, thus only LED1 lights up.



At 'State C', output Q_0 and Q_1 are HIGH, thus LED1 and LED2 light

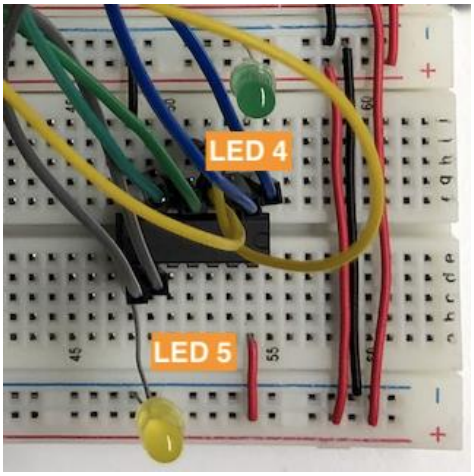


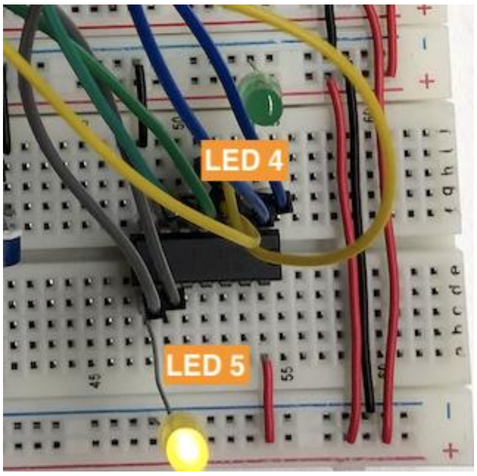
At 'State C', three outputs are HIGH, thus three LEDs light up.

Testing Output Logic

Test points: Two outputs of NOT gate.

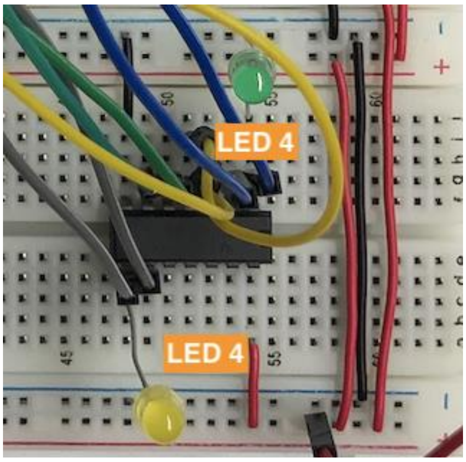
- Attach two LEDs to NOT gate outputs
- High output signal == LED turns on
- Low output signal == LED turns off

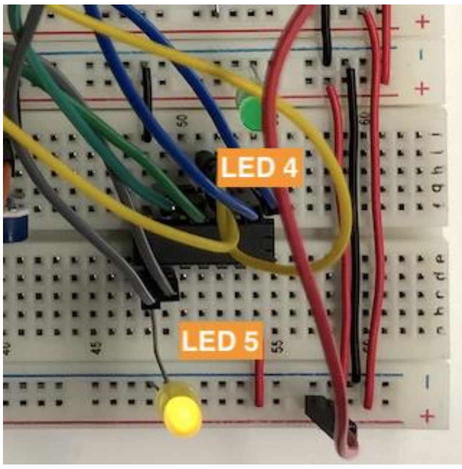




At 'State A', two outputs are LOW, thus no LED light up.

At 'State B', Output A is HIGH, thus only LED5 lights up.





At 'State C', output B is HIGH, thus LED4 lights up.

At 'State D', both outputs are HIGH, thus two LEDs light up.

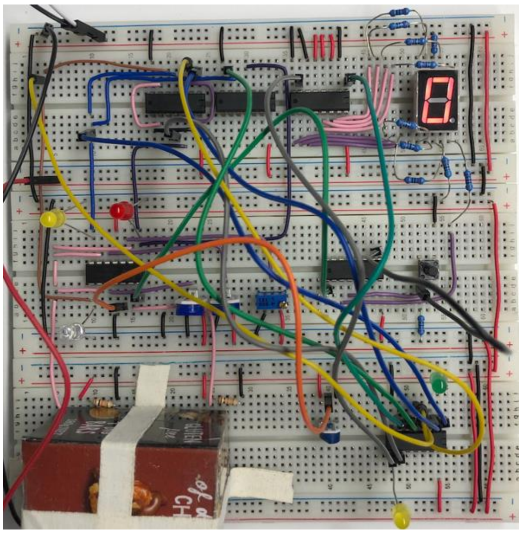
Testing Memory State

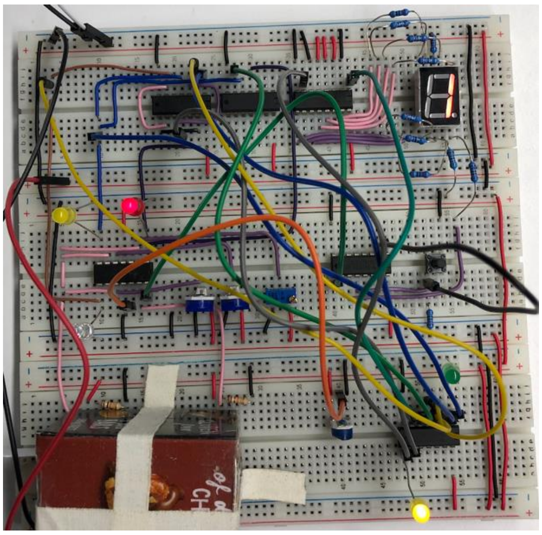
Test points: The flip-flop output Q'.

- If output Q' is LOW, the decimal point LED will turn on.

Integration testing

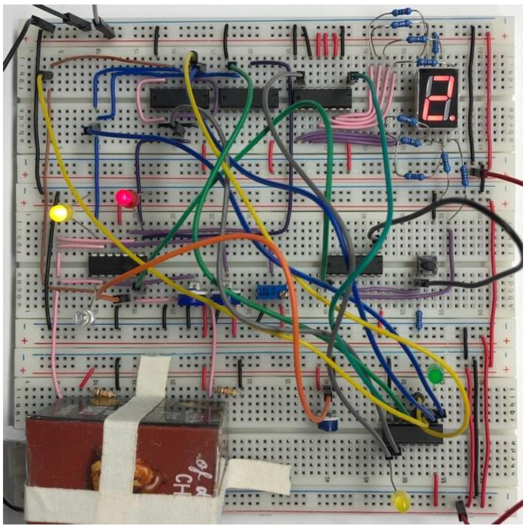
- Connecting three modules together
- Attach LEDs to both inputs and outputs of D Flip-Flop
- See if LEDs behaves correctly as the truth table.
- The 7-seg LED should demonstrate like this:

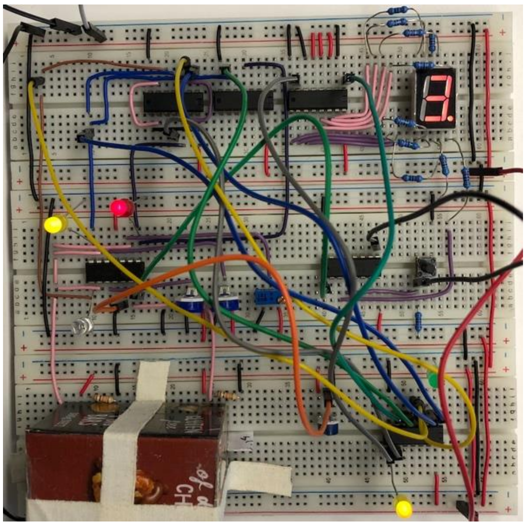




At ‘State A’, the 7-seg LED will display number ‘0’.

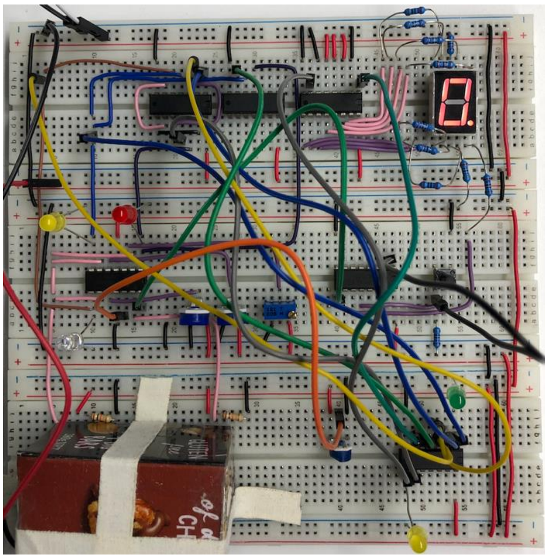
At ‘State B’, the 7-seg LED will display number ‘1’.



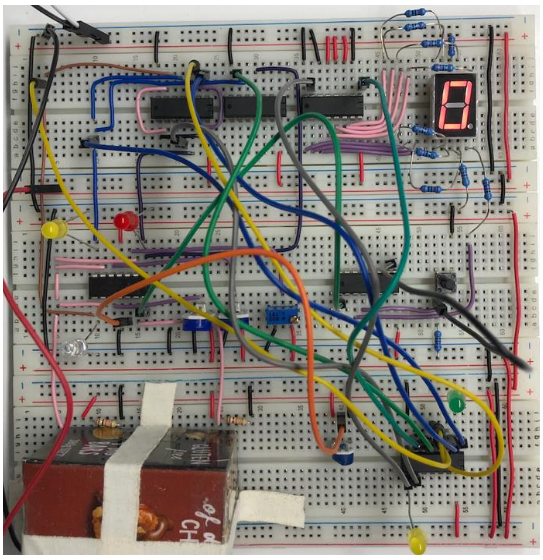


At ‘State C’, the 7-seg LED will display number ‘2’ with decimal point lights up.

At ‘State D’, the 7-seg LED will display number ‘3’ with decimal point lights up.



Pull out the paper, the decimal point LED still lights on which means the state machine still remains in the jammed state.



Press the button to reset, the decimal point LED will be turned off.

Acceptance testing

- ✓ Two low cost dependent resistors as the sensor
- ✓ Single 5V power supply
- ✓ Display corresponding number of sheets of paper
- ✓ Decimal point LED lights up when more than one sheet
- ✓ Push button will be reset (decimal point LED lights off)
- ✓ Appropriate Reference Voltage (4.3V, 3.5V and 2.7V) for op amp V^+ inputs.
- ✓ Each segment of a 7-seg LED have own resistor which is 270Ω
- ✓ Resistors in series with LDR which are 10kΩ
- ✓ Resistors in series with LED on Detector1 & 2 which are 470Ω