Group 6
Network Analysis I
Circuit Design Project

Internal Functionality of a Two-terminal Black Box Using Three LEDs of Different Colors

Funmilayo Oludaiye
Brandon Montgomery
Titilope Ogunlaja

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Problem Statement

The purpose of the project was to design a circuit that would indicate the internal connection of a two-terminal black box by displaying one of these three LEDs: red, green, and yellow. While only two terminals can be accessed externally, the interior circuit of the black box consisted of three terminals A, B, C connected to a voltage source and three resistors with equal resistances.

While terminals B and C are connected to the voltage source with + polarity to B and - polarity to C, only terminals A and B can be accessed from the outside. The resistors will have five different configurations with corresponding LED indications. If the resistors are connected in a delta formation or 1-1-1 format as shown in Figure 1 below, only the red LED will turn on.

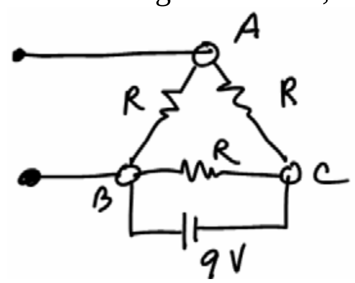

Figure 1: Delta or 1-1-1 formation

On the other hand, when the resistors are connected in either 2-0-1 or 1-0-2, only the green LED will light up as shown in Figure 2.

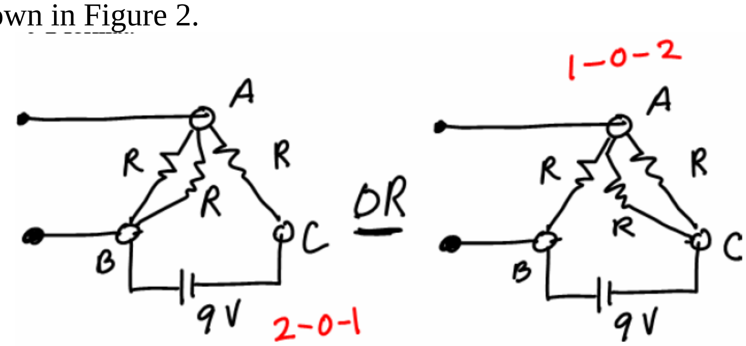

Figure 2: 2-0-1 or 1-0-2 formation

Finally, the yellow LED will only turn on when the resistors are connected in a 3-0-0 or 0-0-3 format as shown in Figure 3.

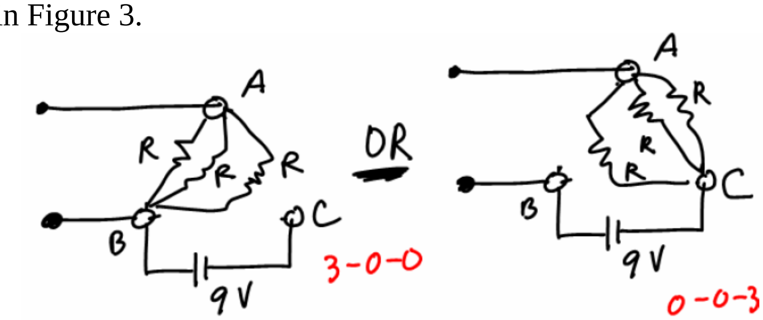

Figure 3: 3-0-0 or 0-0-3 formation

Constraints & Criteria

For the completion of this project, the five resistor formations mentioned were the required but not limited cases. In addition, the parts and equipment used had to be taken from the department; otherwise permission to buy extra parts was required. Another important criterion was the use of fewer components in the circuit. However, the most important criterion for this project was the correct indication by the three LEDs.

In addition, groups were required to follow scheduled steps when documenting the design of the project to avoid disqualification. All submissions were to be electronically in MS Word format, with a 1” margin on all sides, and font size 12 in Times New Roman. In addition, five deliverables: Problem Statement, Initial Circuit Design, Final Circuit Design, Demonstration of the Circuit and Submission of Peer Evaluation had to be submitted on time by their due dates to ensure the project success.

Final Circuit Design

The first task of the group was to analyze each of the five circuits to understand the behaviors of each one. Here, we observed that Node B is always grounded, and the voltage at Node A will vary depending on the configuration of the resistors within the black box. The possible values of Node A are 0V, 3V, 4.5V, 6V, and 9V. These voltages correspond to yellow LED, green LED, red LED, green LED, and yellow LED respectively, as shown in Figure 4 below.

Voltage (V)	OPAMP				LED		
	U4	U3	U2	U1	Red	Yellow	Green
0.0	0	0	0	0	0	1	0
3.0	0	0	0	1	0	0	1
4.5	0	0	1	1	1	0	0
6.0	0	1	1	1	0	0	1
9.0	1	1	1	1	0	1	0

Figure 4: Table showing the voltage and OPAMP conditions to power each LED

We decided to use a comparator to analyze the voltage being applied to Node A because of the different voltages created by each resistor. We began with an LM339 comparator but quickly discovered that the logic and board did not function properly together. Upon further research, we found that the LM324 OPAMP would better serve our needs, so we implemented the design with that comparator instead.

The final circuit uses the four OPAMPs on the integrated circuit and combinational logic to judge if the voltage being applied is within a given range. A series of resistors powered by the 9V battery connected between terminals B and C were used to create the different voltages applied to the OPAMPS. The voltages created, along with their respective OPAMPS, are 7V/U4, 5V/U3, 4V/U2, and 2V/U1.

To simplify the logic, we isolated the logic needed to turn on each individual LED to the highlighted areas of Figure 4 above. The LEDs are powered by the 9V battery on the board and have a 720 ohm resistor connected in series to lower the voltage across the resistor.

How the Circuit Works

Figure 5 below demonstrates the final circuit model and the functionality of the circuit.

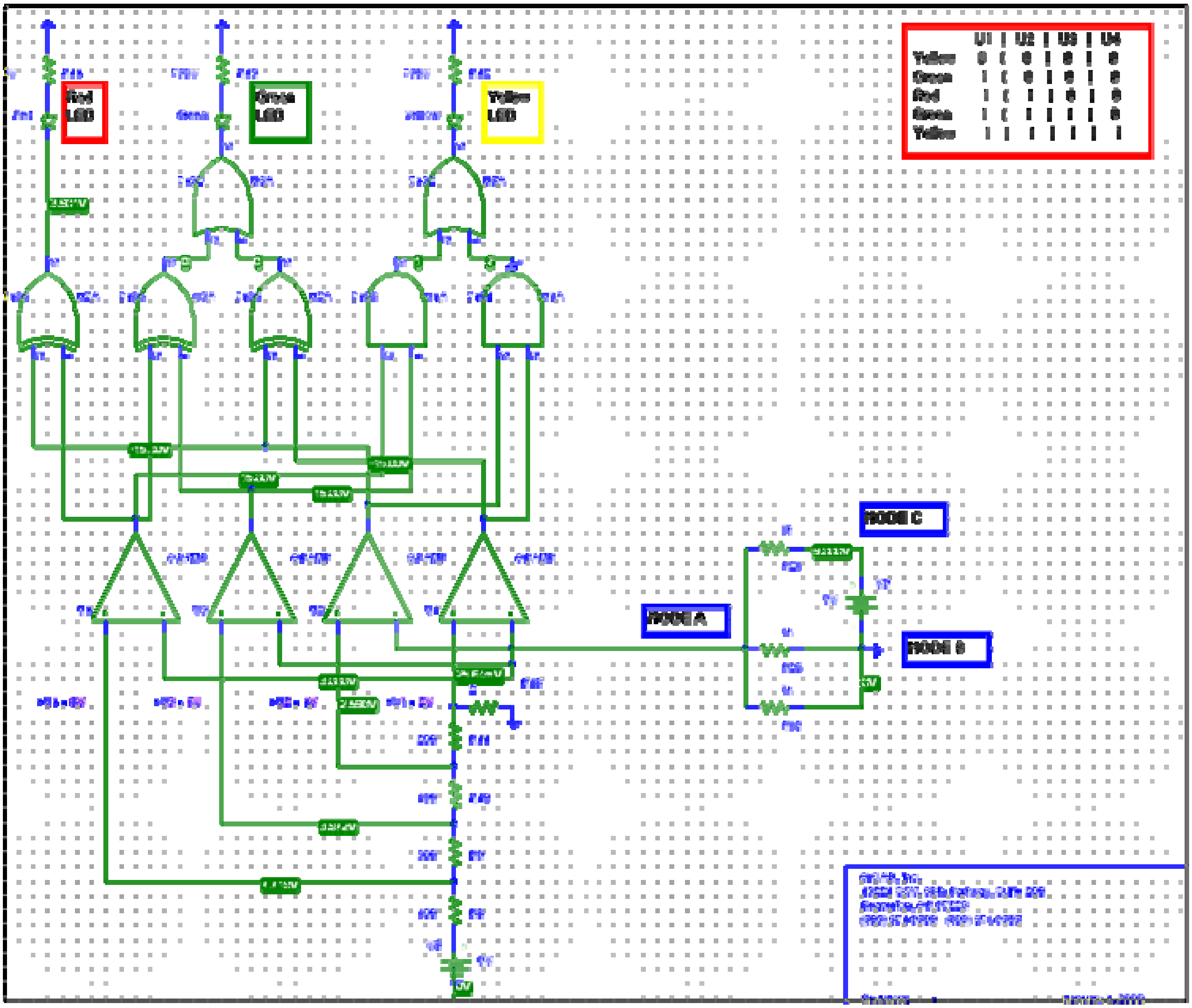

Figure 5: Final Circuit Model

Input voltage from the voltage source (battery) Vcc is 9V and the voltage to compare is the voltage V2 at Node A of the black box. The voltages into the negative terminals of each OPAMP (from Vcc) are respectively 7V for U4, 5V for U3, 4V for U2, and 2V for U1.

When the voltage at Node A of the black box (V2) is 0V (grounded), the voltage out of U1 to the yellow LED is -2V and the yellow LED comes on. When V2 is 3V, the voltage out of U1 to the green LED is 1V and the voltage out of U2 to the green LED is -1V, and it comes on. The same happens for the red LED (V2 = 4.5V, output voltage at U2 = 0.5V, output voltage at U3 = -0.5V) the green LED (V2 = 6V, output voltage at U3 = 1V, output voltage at U4 = -1V), and the yellow LED (V2 = 9V, output voltage at U4 is 2V).

Why Our Project is the Best

Our project is the best for several reasons, the first being that our circuit is very simple in design, implementation, and understanding. We used truth tables to simplify the logic of the circuit and logic gates to eliminate components of the circuit that were not being used at specific times. Our circuit is very simple to operate and understand, while serving the purpose for which it was built, and it even has an added bonus of being aesthetically appealing.

We also used efficient parts in the construction of the circuit such as an operational amplifier (OPAMP) instead of a comparator. We made sure we adequately researched the functions, advantages, and limitations of both the LM339 and the LM324 to determine which of the two would be better suited to the logic of our circuit.

In addition, all of the members of this group worked as a team on the various sections of the project, from the initial circuit design to the building of the actual project, despite the fact that a former member of the group dropped the class right after we had started the project. One thing about this group is that each one of us can say that we specifically improved our circuit design skills and technologies, while employing the knowledge we learned from intra-disciplinary classes for solving circuit-related problems.

Finally, and most importantly, Group 6 fulfilled all objectives and satisfied all constraints specified in the problem statement of the project. Only available elements, parts, and equipment available from the department were used in constructing the circuit, and upon completion of the project, the circuit successfully performed the task that was required of it (lighting the three LEDs five different times under different conditions).