جامعة خليفة
Khalifa University

Department of Electrical Engineering and Computer Science

ELECTRONIC CIRCUITS AND DEVICES LAB – ECCE 312 Spring 2023

Course Project
Police Siren Light/ Dancing Light using BJT

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Laboratory Section: **02** Date of Experiment: **20/11/2023**

No.	Criteria	Description	Weight %	Mark	Comments
1.	Design and Analysis	Design and analysis of the results with detailed steps. Analysis of the questions	**1+1**		
2.	Multisim Simulation	How well the executions are done, neatness, clear capture, etc.	**2**		
3.	Practical	Implementation of your verified Design	**2**		
4.	Report presentation	The overall presentation of the report includes an Abstract, Conclusion, Analysis, Layout, and Clarity of figures, Tables, and Graphs as suggested in the report format. Also, the Correct use of the English language.	**2**		
5	Task-B	Multisim Simulation Explanation / Report	**2 (1+1)**		
	Total		**10**		

Abstract

This report aims to utilize our understanding gained from the course Electronic Circuits and Devices to design and simulate a circuit that uses bipolar junction transistors (BJTs) to create a police siren light and dancing light. For the dancing light circuit, an astable multivibrator design was used and modified with the addition of ten LEDs total—five blue and five red connected in series with the transistor. The circuit design was analysed using the simulation software, Multisim, and experimental testing. The frequency of the astable multivibrator circuit (visualized by the rate of flickering of the LEDs) was also studied, where two cases of the astable multivibrator circuit were examined, and changes in the LEDs' flickering rates were noted and discussed. As demonstrated by the oscilloscope waveforms, measurements, and the results reported, the designed circuit's functionality was found to correspond with the expected properties of an astable multivibrator.

Keywords: Astable multivibrator, BJTs, Multisim, Police siren.

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1. Introduction

1.1 Aims and Objectives.

- To design a police siren light circuit using an astable multivibrator and BJT in Multisim.
- To build and implement the designed circuit.
- To analyse the circuit and give methods for adjusting the flickering rate of LEDs.
- To investigate how flickering intensity and frequency can be adjusted when two different colour LEDs are used.
- To modify the circuit for 20 LEDs and ensure that it operates within the maximum voltage specified.

1.2 BJT

A bipolar junction transistor, shown in figure 1, is a three-terminal semiconductor device with the following connections: base, emitter, and collector. The device is made up of two P-N junctions that can amplify a signal. As a result, the BJT can be used as switches or amplifiers. BJTs are widely used in electronic devices such as televisions and mobile phones. There are three regions of operation for the BJT which are cutoff, saturation and active forward.

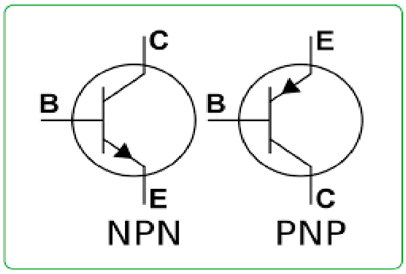

Figure 1. connections of BJT

The transistor is in cutoff when the base current (I_B) is zero, indicating that the emitter-base (E-B) junction is either reverse-biased or unbiased (open-circuited). The collector current (I_C) is zero in this state, and the collector-emitter voltage (V_{RC}) and collector-emitter voltage (V_{CE}) are both equal to the supply voltage (V_{CC}).

The transistor operates in either the active or saturation region when the E-B junction is sufficiently forward-biased, allowing I_B to flow. The collector current (I_C) in the active region is given by I_B, where is the common-emitter current gain. As I_B increases, so does I_C until it reaches its saturation point (I_{Csat}). I_C is at its maximum during saturation, and further increases in I_B do not result in an increase in I_C. As a result, V_{CE} approaches 0V. Figure 2 summarizes the three regions of operation.

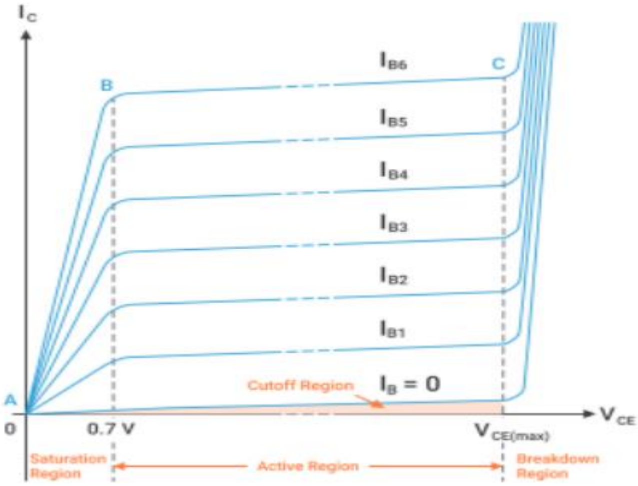

Figure 2. BJT regions of operation

1.4 LED Characteristics and Connections

A light-emitting diode, or LED, is a semiconductor component that emits light when an electrical current is passed through it. Light is emitted when electrons recombine with holes as current flows. LEDs are designed to allow current flow in one direction while preventing it in the other. LEDs have low power consumption, high efficiency, and long lifespan.

Highly doped p-n junctions make up light-emitting diodes (LEDs). When forward biased, the colour of light emitted by an LED is determined by the semiconductor material used and the degree of doping. In the diagram, an LED is enclosed within a transparent cover, allowing the produced light to be emitted outwardly.

1.5 Astable Multivibrator

1.5.1 The Working of an Astable Multivibrator

An astable Multivibrator, shown in figure 3, is a free-running oscillator that oscillates between two states to generate two continuous square wave output signals. It operates as a two-stage amplifier with positive feedback, with the output of one amplifier influencing the output of the other. This feedback drives one transistor in the circuit into saturation (On state), while the other is driven into cut-off (OFF state). The circuit conditions reverse after a certain time, causing the saturated transistor to turn off and the cut-off transistor to turn on.

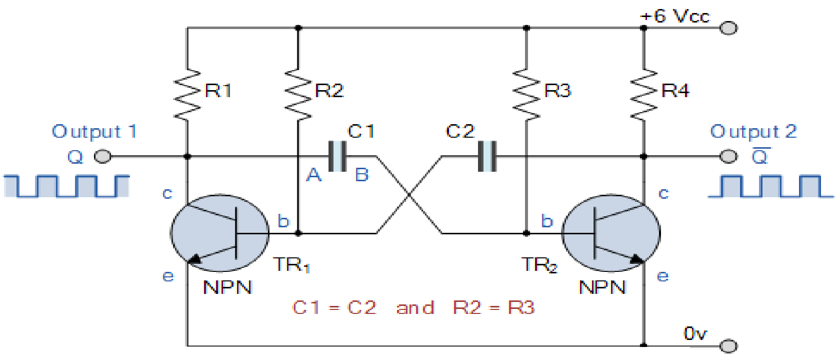

Figure 3. Circuit design of astable multivibrator

The details of the working of the circuit are as follows. When the voltage across capacitor C1 reaches 0.7 volts, it triggers the saturation of the Q2 transistor as C1 charges through R1. Q2's base saturation reduces the collector current, causing a voltage drop applied to the base of Q1 through C2. This results in a reverse bias for Q1, leading to an alternating saturation and cut-off state for Q1 and Q2, respectively. Point A maintains a VCC voltage while R2 charges capacitor C2. Once the voltage across C2 reaches 0.7 volts, Q1 transistor turns on, goes through saturation, and then cuts off. The switching states of the transistors are determined by the biasing resistor and capacitor values, commonly referred to as RC values. The outcome is a square waveform exhibiting a peak amplitude of VCC, with both transistors operating in an alternating manner.

1.5.2 The Frequency of an Astable Multivibrator

The on and off turning of the transistors Q1 and Q2 depends on the voltages seen at their base terminal with respect to ground, V_{BE1} and V_{BE2}, respectively. These voltages are connected to an RC network controlling the duration at which each transistor is on. Considering only transistor Q2, figure 4 shows the V_{BE2}'s connection to the R_Q2 and CQ_2 network.

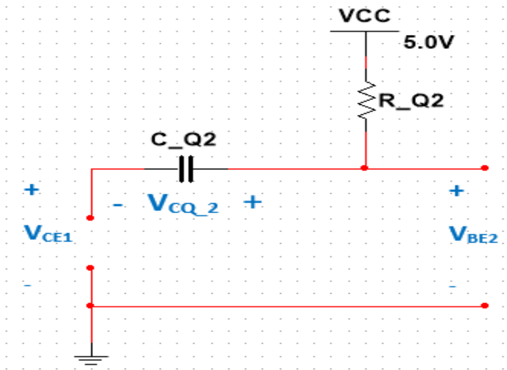

Figure 4. The circuit seen by the base terminal of the transistor Q2.

Voltage across V_{BE2} is controlled by voltage across the capacitor, therefore we may use the general formula for voltage across the capacitor given by Eq. 1 to derive the V_{BE2} equation.

$$V_c(t) = V_c(\infty) + (V_c(0) - V_c(\infty)) \times e^{-\frac{t}{RC}} \qquad (1)$$

Assume t<0 is when Q1 is off and Q2 is on. When Q1 is at cutoff, V_{CE1} is maximum and is equal to V_{CC}. When Q2 is on, V_{BE2} is 0.7V. Hence $V_{CQ\_2}(0) = -V_{CE1}(0) + V_{BE2}(0) = \mathbf{-V_{CC} + 0.7V}$.

Assume t>0 is when Q1 is on and Q2 is off. When Q1 is at saturation, $V_{CE1} \approx 0V$, and using the loop connecting V_{CC}, R_Q2, and V_{CE1}, at infinity, the capacitor would charge to the input voltage, i.e., $\mathbf{V_{CQ\_2}(\infty) = V_{CC}}$. When Q1 is on, $V_{BE2}(t) \approx V_{CQ_2}(t)$, (as $V_{CE1} \approx 0V$), hence the equation for V_{BE2} is formulated as given below.

$$V_{BE2}(t) \approx V_{CQ_2}(t) = V_{CC} + (-V_{CC} + 0.7 - V_{CC}) \times e^{-\frac{t}{R\_Q2*C\_Q2}}$$

$$V_{BE2}(t) \approx V_{CQ_2}(t) \approx V_{CC} - 2V_{CC} \times e^{-\frac{t}{R\_Q2*C\_Q2}}$$

When Q1 is on, Q2 is off, and vice versa. Q2 is on when V_{BE2} is 0.7V, assuming for simplicity Q2 is on when V_{BE2} is 0V, then setting V_{BE2} to 0V and solving for t, given by Eq.2, is the time required for the capacitor to charge to 0V, turning Q2 on, or the duration at which Q1 is on. Given **R_Q1= R_Q2, and C_Q1 = C_Q2**, then, the period of the turning on and off the transistors is given by Eq.3, which is (2*t_{Q1_on}), to account for both durations at which the transistor is on and off. Furthermore, the frequency is the inverse of T, given by equation 4.

$$t_{Q1\_on} = \ln(2) \times R\_Q2 \times C\_Q2 \tag{2}$$

$$T = 2 \times \ln(2) \times R\_Q2 \times C\_Q2 \tag{3}$$

$$f = \frac{1}{2 \times \ln(2) \times R\_Q2 \times C\_Q2} \tag{4}$$

1.6 The Frequency of the Police Siren Circuit

The police siren circuit implements two different colour LEDs, blue and red, which have somewhat significantly different forward voltages (3.7V vs. 2V), affecting the intensity of the flickering of the LEDs. The section above derived the simplified frequency equation of an astable multivibrator. The differences between the police siren and the astable multivibrator frequency equations would be because of the different V_{CE} transistor voltages for each circuit, which in turn affects the capacitor charging equations. For the multivibrator circuit, when the transistor is operating on the cutoff region, the V_{CE} voltage is equal to V_{CC}, as the transistor is on series with a resistor; on the other hand, for the police siren circuit, when either transistor is off and operating at the cutoff region then the V_{CE} voltage of the transistor is not equal to V_{CC} nor is it the same for both transistors, this because the transistors are connected in series to LEDs of different forward voltages. Although the transistors are off, the LEDs are on due to the V_{CC} connected at their positive terminals, and due to the flow of leakage current, consequently, they have a voltage drop across them; the equation for V_{CE} then becomes $V_{CE} = V_{CC} – V_{K\_LED}$. Multisim circuits shown in Figures 5 and 6 support this finding.

For the derivation of the $\mathbf{V_{BE2}}$ equation (see section above), the $\mathbf{V_{CQ\_2}(\infty) = V_{CC}}$**,** and for the branch with the **red LEDs** $V_{CQ\_1}(0)$ is calculated as shown below, **(**from figure 5, $V_{K,\,R\_LED} = 0.7V$.)

$V_{CQ\_2}(0) = -V_{CE1}(0) + V_{BE2}(0) = -(V_{CC} – V_{K,\,R\_LED}) + 0.7V = -(V_{CC} - 0.7V) + 0.7V = \mathbf{-V_{CC} + 1.4V}$

For the derivation of the $\mathbf{V_{BE1}}$ equation, $\mathbf{V_{CQ\_1}(\infty) = V_{CC}}$, and for the branch with the **blue LEDs,** $V_{CQ\_1}(0)$ is calculated as shown below, **(**from figure 6, $V_{K,\,B\_LED} = 2.8V$).

$V_{CQ\_1}(0) = -V_{CE2}(0) + V_{BE1}(0) = -(V_{CC} – V_{K,\,B\_LED}) + 0.7V = -(V_{CC} - 2.8V) + 0.7V = \mathbf{-V_{CC} + 3.5V}$

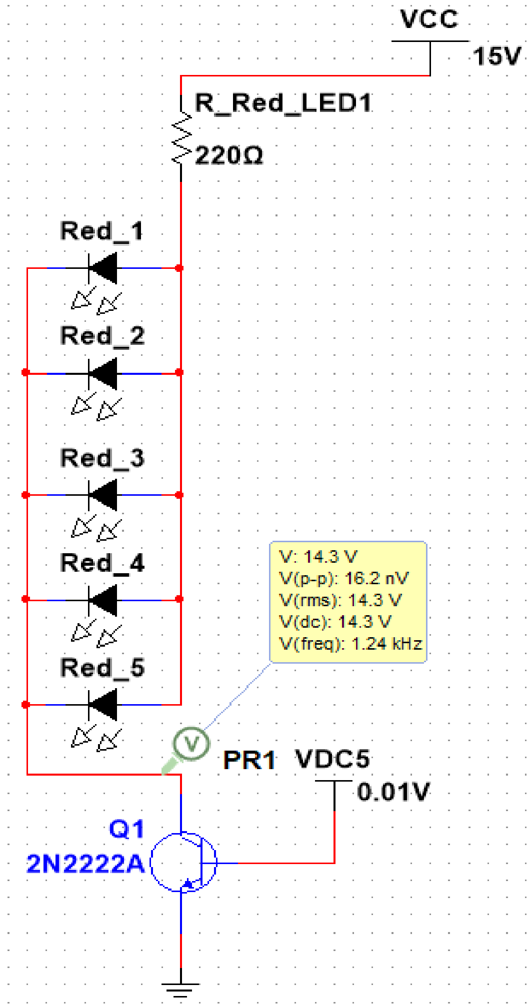

Figure 5. Multisim circuit showing V_{CE} when the transistor in series with red LEDs in the off state.

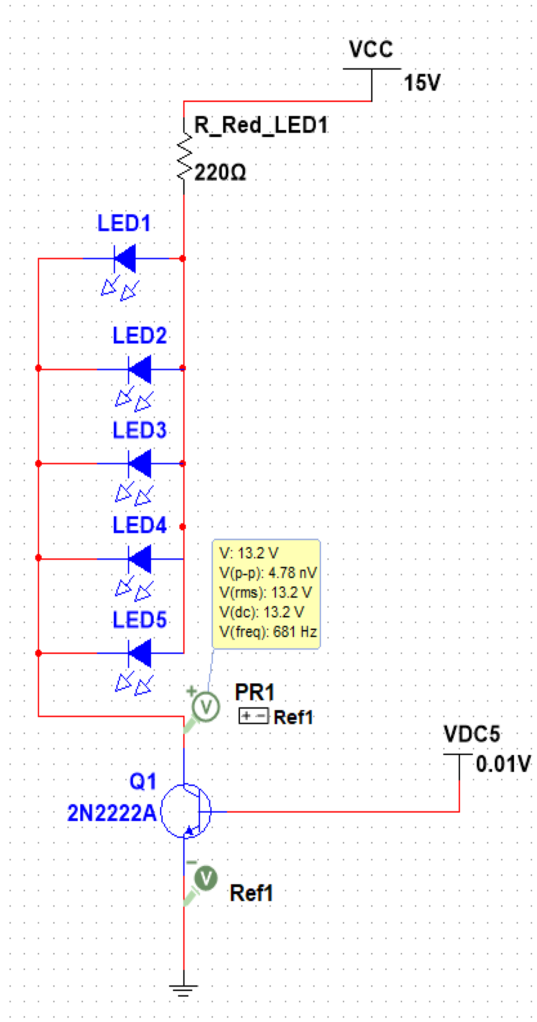

Figure 6. Multisim circuit showing V_{CE} for a transistor in series with blue LEDs in the off state.

The resulting equations for V_{BE1} and V_{BE2} are given below. Assuming C_Q1 = C_Q2, and R_Q1 = R_Q2, the frequency derived from the equations given below (explained in the section above) would be different for each equation, it hence can be interpreted that the time required for C_Q1 to charge to 0.7V is different from that for C_Q2, resulting in the adjustment of the frequency of the circuit, and the resulting frequency will be somewhat different from the simplified equation given in section 1.5.2; this also means that the frequency of the police siren circuit depends on both the RC network and the forward voltages of the LEDs used.

$$V_{BE2}(t) \approx V_{CQ_2}(t) = V_{CC} + (-V_{CC} + 1.4) \times e^{-\frac{t}{R\_Q2*C\_Q2}}$$

$$V_{BE1}(t) \approx V_{CQ_1}(t) = V_{CC} + (-V_{CC} + 3.5) \times e^{-\frac{t}{R\_Q1*C\_Q1}}$$

2. Detailed Circiut Design

The design of the astable multivibrator requires three essential considerations. First, the LEDs' connections, whether parallel or series. Second, the calculation of the resistors to limit the current flow through the LEDs to less than 20mA. Finally, the components that control the flickering rate of the LEDs (or the frequency of the astable multivibrator). Each consideration is discussed below.

2.1 LEDs' Connections

The required design specifies using five blue and red LEDs. The threshold or forward voltage of red LEDs ranges from 1.6V to 2V. The forward voltage of the blue LEDs ranges from 2.6V to 3.7V. As the design also requires using a 15V power supply, connecting five red LEDs in series requires less potential drop than the power supply and is hence possible; however, connecting five blue LEDs in series would require more potential than the supplied voltage; consequently, the voltage is not equally distributed among the LEDs making some more bright than others. Thus, it is required to connect the LEDs in parallel instead such that all LEDs have an equal potential drop.

2.2 The LED's Current Limiting Resistors

To avoid burning out the LEDs and for longer performance, the current flowing through them must not exceed 20mA; this is achieved by connecting a single resistor in series to the parallel connection of the LEDs. While it is also possible to connect a resistor in series with each LED, the former choice is preferred as it is easier to implement a circuit with fewer resistors. Moreover, if a current of **10mA** is desired through each LED, the total current flowing through the resistor is 5 ×10mA or **50mA;** the potential drop across the resistor is the difference between the forward voltage of the LED and the power supply voltage (**assuming** the transistor in the on state has $V_{CE} = 0V$). The equation for calculating the resistor is given in Eq. 5.

$$R = \frac{Vcc - V_k}{I_{tot}} \tag{5}$$

Hence, the resistor in series with the parallel combination of the blue and red LEDs can be calculated, as shown below. The calculated resistors can be substituted for a commercially available resistor of value **220*Ω***; this changes the estimated current flowing through the blue LEDs to 10.36mA and 12mA for the red LEDs, which should turn on the LEDs with satisfactory brightness.

$$R_{blue} = \frac{15V - 3.6V}{50\ mA} = 228\ \Omega$$

$$R_{red} = \frac{15V - 1.8V}{50\ mA} = 264\ \Omega$$

2.3 Components Controllecting the Flickering Rate

As mentioned in the introduction, the frequency of the astable multivibratror depends on the RC network connected across the base terminal of the transistors, proved by the derivation of the equations for its period and frequency shown in section **1.5.2.** The equations can also be rewritten in terms of $\boldsymbol{\tau}$, the time constant of the RC network, as shown below, with R_Q1 = R_Q2, and C_Q1 = C_Q2. Note that the simplified equation of the frequency and period of the police siren circuit does not account for the effects of using two LEDs of different colours (as discussed in detail in section 1.6).

$$T = 2 \times \ln(2) \times \tau$$

$$f = \frac{1}{2 \times \ln(2) \times \tau}$$

To study how the RC network controls the frequency, two cases of the multivibrator circuit with different RC networks are to be examined. In the first case, the resistors and capacitors of the RC network are **(R = 20kΩ, C = 2.2μF),** and in the second case **(R = 20kΩ, C = 22μF).** Note that the selected R and C are based on commercial availability and such that the resulting flickering of the LEDs is observable by the naked eye. If the time constant $(R \times C)$ is set very small, then the frequency can be so high that no flickering of the LEDs is noticed.

While it is possible to control the flickering rate by changing either R or C, we choose to change the capacitor only. For the change in the frequency to be evident to the observer, the second case capacitor is larger by a factor of 10. The following section summarizes the components and equipment needed for the experimental implementation.

3. Equipment / Components Used

- Two 2N2222 NPN Transistors.
- Two 2.2µF Capacitors.
- Two 22µF Capacitors.
- Two 220 Ω.
- Two 20 kΩ.
- Ten LEDs (Five Blue LED, Five Red LED);
- Probes, Wires, Connectors.
- Oscilloscope; and
- NI- Elvis Workstation.

4. Simulation

This section discusses the Multisim or simulation results for an astable multivibrator using five blue and red LEDs with a power supply of 15V. Two cases of the design with different RC - networks are then studied. Moreover, the circuit is also re-designed with ten blue and red LEDs with a power supply of 25V.

4.1 Main Circuit Schematics

Figure 7 shows the Multisim schematic of the design implementing the RC network of the first case **(R = 20kΩ, C = 2.2μF)**. The figure shows channels of the oscilloscope to be connected at the positive terminals of the LEDs (reading the measurements with respect to the ground). Channel one reads at the positive terminals of the blue LEDs, while channel two reads at the positive terminals of the red LEDs. Figures 8 and 9 show the Multisim oscilloscope results taken; Figure 8 displays the frequency, period, maximum, and minimum voltage readings of channel one, while Figure 9 shows the same measurement readings for the second channel. The maximum and minimum voltages are measured to better analyse the working of the circuit.

To analyse the change in the flickering rate of the LEDs, the multivibrator circuit with the RC network of the second case (**R = 20kΩ, C = 22μF**) was also implemented. With no change made to the oscilloscope probe connections, Figures 10 and 11 depict the Multisim oscilloscope results captured; Figure 10 displays the oscilloscope readings of channel one, and Figure 11 shows that of channel two.

When the circuit was initially implemented using 2.2 µF capacitors, the LEDs exhibited flickering. Upon transitioning to 22 µF capacitors, a significant reduction in the flickering rate was noted. Moreover, it is observed that the oscilloscope outputs waveforms are altenating at a different frequency for each case between a maximums of 15 V and a minumum of 2.95 V for channel one and 1.65 V for channel two.

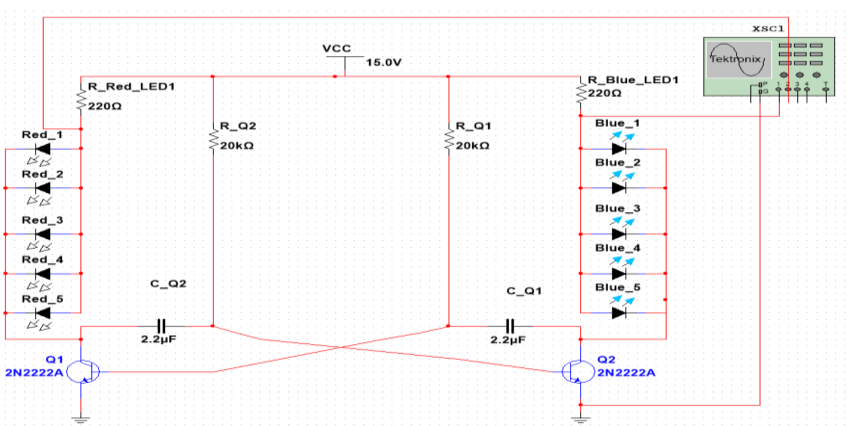

Figure 7. The Multisim schematic of the design, case 1 (R = 20kΩ, C = 2.2μF).

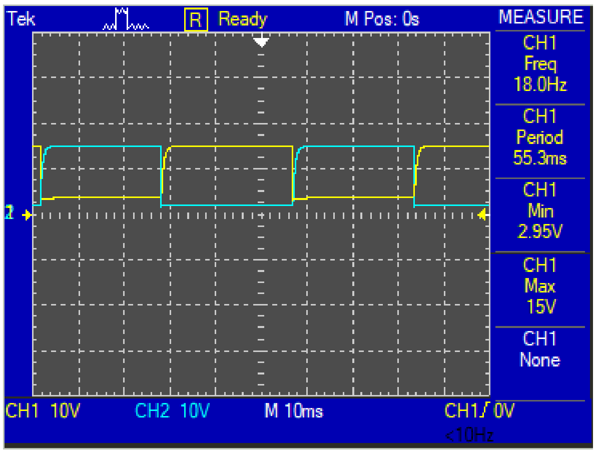

Figure 8. The Multisim oscilloscope results showing channel 1 measurements (connected across blue LEDs, case 1 (R = 20kΩ, C = 2.2µF).

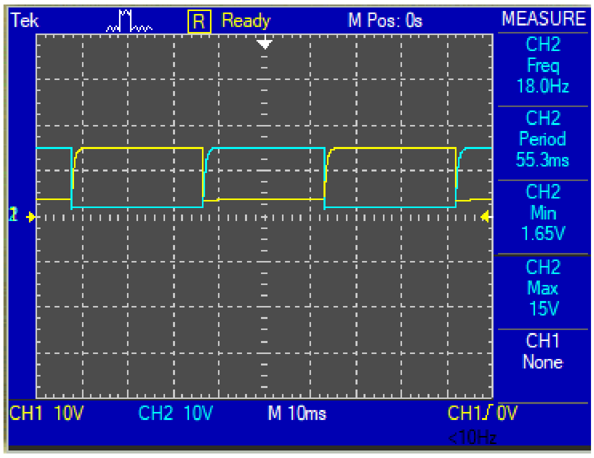

Figure 9. The Multisim oscilloscope results showing channel 2 measurements (connected across red LEDs, case 1 (R = 20kΩ, C = 2.2µF).

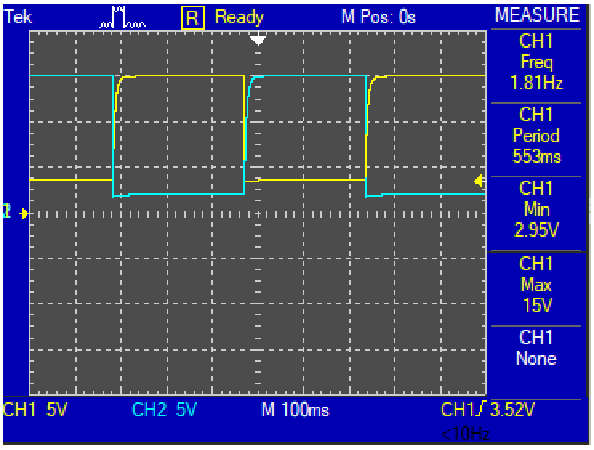

Figure 10. The Multisim oscilloscope results showing channel 1 measurements (connected across blue LEDs, case 2 (R = 20kΩ, C = 22µF).

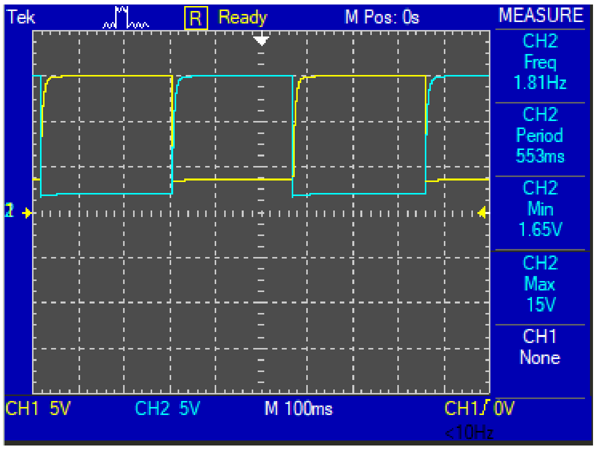

Figure 11. The Multisim oscilloscope results showing channel 2 measurements (connected across red LEDs, case 2 (R = 20kΩ, C = 22µF).

4.2 Circuit Re-design for 20 LEDs.

To redesign the circuit for 20 LEDs, an important consideration is the LEDs' connections, whether parallel or series; this decision is influenced by the forward voltage requirements of the blue LEDs (which are larger than those of the red LEDs). In a series configuration, the voltage drops across each component add up, and with blue LEDs having a higher forward voltage than the supplied voltage, it would result in an insufficient voltage across the LEDs in the series chain. On the other hand, connecting the LEDs in parallel allows each LED to have equal voltage drops, ensuring that each LED receives an appropriate forward bias voltage, meeting its operational requirements.

To accommodate the changing current requirements due to the increase in the number of LEDs, the required resistors are re-calculated using equation 5, where the total current is No. LEDs × 10mA (the desired current flowing through the LEDs) which is 10 × 10mA or **100mA**. The resistor values are calculated as shown below.

$$R_{blue} = \frac{25V - 3.6V}{100\ mA} = 214\ \Omega$$

$$R_{red} = \frac{25V - 1.8V}{100\ mA} = 232\ \Omega$$

Using the same RC network of case one (R=20k and C= 2.2uf), the circuit constructed in Multisim is shown in Figure 12. The oscilloscope result is shown in Figure 13. Comparing the circuit for 10 LEDs to the redesigned circuit for 20 LEDs, it becomes apparent that the frequency and period remained almost the same (**18Hz vs. 17.3Hz, and 55.3ms vs. 57.7ms**), confirming that the frequency of the astable multivibrator is mainly dependent on the RC network; variations are due to the effects of the change on the forward voltage drops of the LEDs (**1.65V vs. 1.58V for red LEDs, and 2.95V vs. 2.89V for blue LEDs**), which are dependent on the current flowing through the LEDs. The general behavior of the astable multivibrator circuit, as reflected in the oscilloscope output, showed consistency. The prominent difference in the redesigned circuit only lay in the resistor values, which had to be adjusted.

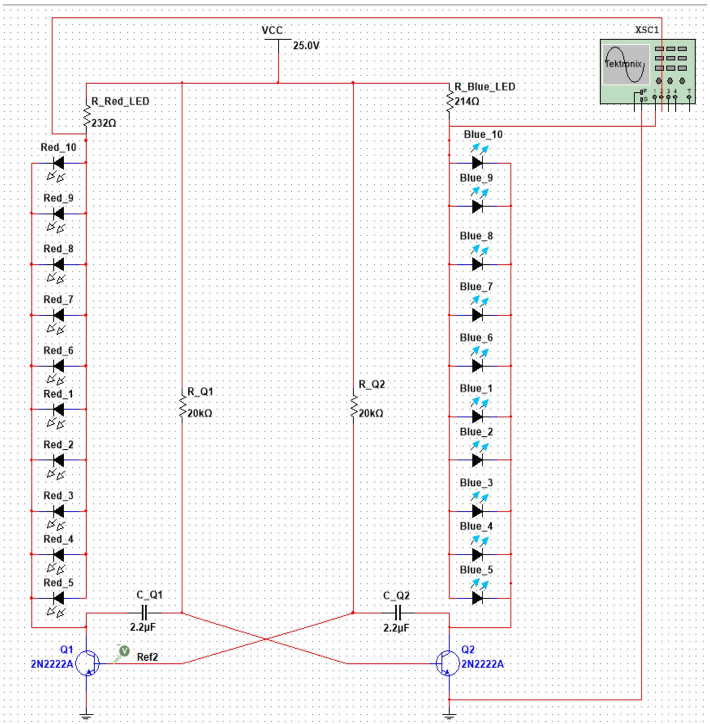

Figure 12. BJT Dancing 20 LED mutism simulation.

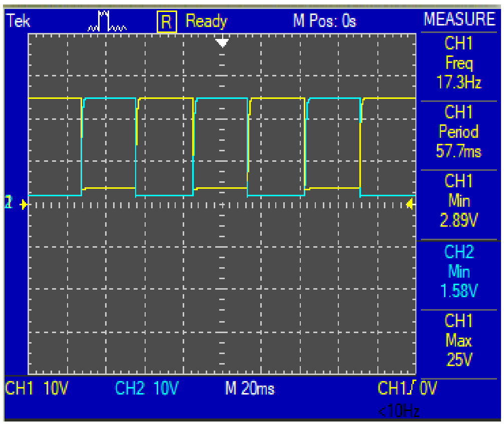

Figure 13. Oscilloscope results of BJT Dancing 20 LED mutism simulation.

5. Experimental procedure

The objectives of the experimental procedures are to study the change in frequency of the LEDs flickering when changing the RC network of the multivibrator circuit and observe the general behaviour of an astable multivibrator. For that, the Multisim circuit shown in Figure 7 (which implements the case one RC circuit, **R = 20kΩ, C = 2.2μF**) was first built on the NI ELVIS breadboard, as shown in Figure 14. After finishing the circuit implementation, the circuit was powered with a 15V source from the breadboard. The circuit was successfully assembled to observe the flickering LEDs. The oscilloscope readings, which are the period, maximum, and minimum voltages taken for both channels one and two are shown in Figure 15. After that, the 2.2μF capacitor was replaced with a **22μF** capacitor, changing the RC network to that of case 2. The oscilloscope readings captured are shown in Figure 16. The oscilloscope waveform pulses closely resemble square waves that are out of phase. Moreover, the observed reduction in the flickering rate of the LEDs as the capacitor is changed is depicted in the attached video link: https://youtu.be/13ceyV_Shco.

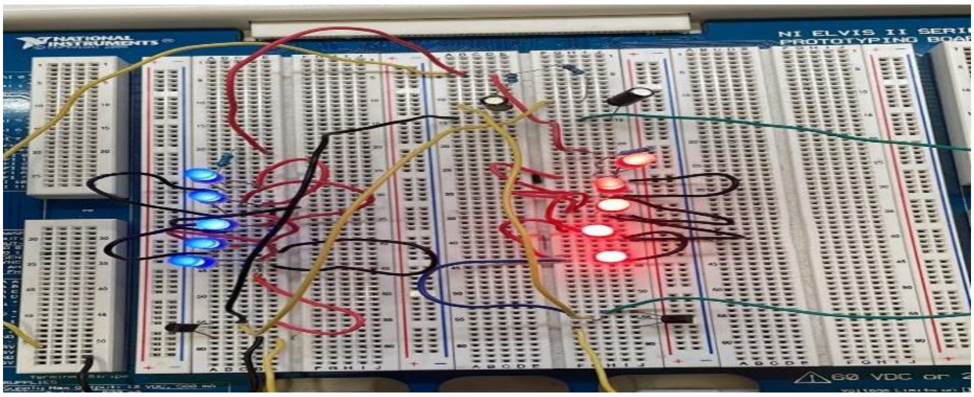

Figure 14. Astable multivibrator circuit implemented in the breadboard, case 1 (R = 20kΩ, C = 2.2μF).

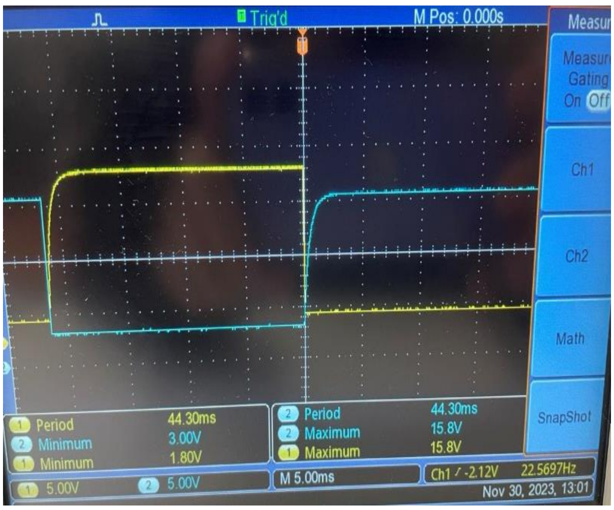

Figure 15. The Multisim oscilloscope results showing channel 1 and 2 measurements, case 1 (R = 20kΩ, C = 2.2μF).

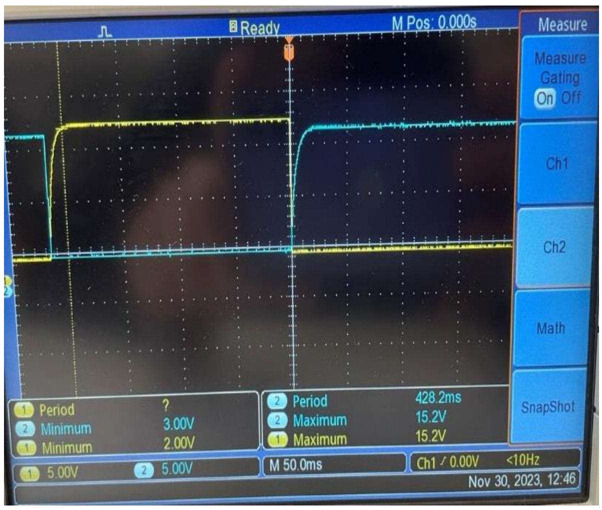

Figure 16. The Multisim oscilloscope results showing channel 1 and 2 measurements, case 2 (R = 20kΩ, C = 22μF).

6. Results Analysis and Discussion

This section compares and discusses theoretically expected results, simulation results, and practical results of the experimental implementation.

6.1 Period and Frequency of the Astable Multivibrator

The period and the frequency of the oscillation state of the LEDs were derived in section **1.5.2** of the introduction. As stated above, those variables are controlled by the RC network of the circuit. The calculated, Multisim and practical results of the period and frequency are discussed for each case below.

Using the equations given in the introduction, the period and frequency of the astable multivibrator can be **calculated** as follows.

- Case 1: (R = 20 kΩ, C = 2.2uF)

$$T_{calculated\_case\_1} = 2 \times \ln(2) \times R\_Q2 \times C\_Q2 = 2 \times \ln(2) \times 20 \times 10^3 \times 2.2 \times 10^{-6} = \mathbf{60.996\ ms}$$

$$f_{calculated\_case\_1} = \frac{1}{T_{calculated\_case\_1}} = \frac{1}{60.996 \times 10^{-3}} = \mathbf{16.394\ Hz}$$

- Case 2: (R = 20 kΩ, C = 22uF)

$$T_{calculated\_case\_2} = 2 \times \ln(2) \times R\_Q2 \times C\_Q2 = 2 \times \ln(2) \times 20 \times 10^3 \times 22 \times 10^{-6} = \mathbf{609.970\ ms}$$

$$f_{calculated\_case\_2} = \frac{1}{T_{calculated\_case\_2}} = \frac{1}{609.97 \times 10^{-3}} = \mathbf{1.6394\ Hz}$$

Table 1. summarizes the theoretical, simulation and practical results of the period and frequency for each implemented case. It also includes the percentage of error calculated using Eq. 6.

$$\%\ of\ error = \frac{|Simulation. - Experimental\ |}{Simulation} \times 100 \tag{6}$$

Table 1. Theoretical, simulation, and practical results the period and frequency.

Measurement	Theoretical results	Simulation results	Practical results	Percentage of error
Case 1: (R = 20 kΩ, C = 2.2uF)				
Period	60.996 ms	55.3 ms	44.3 ms	19.892%
Frequency	16.394 Hz	18 Hz	22.6 Hz	25.556%
Case 2: (R = 20 kΩ, C = 22uF)				
Period	609.97 ms	553 ms	428.2 ms	22.568%
Frequency	1.64 Hz	1.81 Hz	2.36 Hz	30.387%

It can be observed from the table that, in case two, increasing the capacitance by a factor of 10 increased both the theoretical and simulation periods by 10, and the frequency decreased by the same amount. The practical result of the period also increased, specifically by 428.2 ms/44.3ms ≈ 9.67, or almost 10.

The time constant of case one circiut is ($\boldsymbol{\tau = R \times C = 0.044\ s}$), while the time constant of case two is ten times greater, or **0.44s.** The larger the time constant, the slower the charging and discharging of the capacitor through the resistor. In the case of the astable multivibrator, increasing the time constant (case two) means more time is required for the capacitor to charge to 0 V (simplification of 0.7 V), turning the connected transistor on (hence LEDs), and thus the lower is the frequency or flickering rate of the LEDs. The conclusion made is that the time constant is inversly propotional to the frequency of the flickerings of the LEDs.

Moreover, it can be observed that there is little difference between theoretical and simulation results; this is due to the simplifications and assumptions made when deriving the equations of the frequency and period of the astable multivibrator (discussed in sections **1.5.2** and **1.6**). Hence, practical results are correctly expected to be nearer to the simulated results than theoretically calculated results.

The percentage of error calculated in the last column of the table is moderately high; one reason possible factor may be because the expected frequency is insignificant, making it harder for the oscilloscope to detect it. Further, it can be marked in Figure 14 that there is a question mark for the reading of the channel two period (although the channel one period is given and should be equal to that of channel two, as supported by Multisim results). Additionally, variation from simulated results may be due to the type of transistor used and its particular manufactured characteristics, as not all transistors are exact. Also, the power supplied by the NI-Elvis station may not always be 15V, and additional resistances due to wires and equipment used may also explain the error percentage.

6.2 Maximum and Minimum Voltages Measured at the LEDs' Anodes

As mentioned above, in the Multisim and experimental implementation, the oscilloscope probes are connected across the positive anodes of the LEDs; hence, as the astable multivibrator turns a transistor on, the LEDs are forward biased, the transistor acts like a short circuit with approximately zero potential drop, and the voltage read should be the knee voltage of the particular LED. When the astable multivibrator turns a transistor off, the transistors act like an open circuit; hence, no current flows through the LEDs, and the voltage measured should equal the supply voltage. Note that changing the capacitors of the RC network should not change those measurements.

Ideally, the oscilloscope output should alternate from 15V to a value in the range of 2.5 - 3.7V for the channel connected at the anodes of the blue LEDs, and the channel output at the red LEDs should alternate from 15V to a value in the range of 1.6 - 2V. When one transistor is on ($V_{o1} = V_k$), the other is off, and V_{o2} = 15V.Showing that when one transistor is active, the other is inactive. As a result, when the LEDs on one side are illuminated, the LEDs on the opposite side are turned off. This behaviour was noted in the Multisim and experimental procedures sections.

The simulation results given in Figures 8 and 10 (results unchanged with different cases) show that the channel connected across the blue LEDs has a minimum voltage of 2.95 V and a maximum of 15V. The practical results of the same connection, shown in figures 15 and 16, measure the minimum to be 3V (for both cases) and the maximum to be 15.8V for the first case (C_Q1 = C_Q2 = 2.2uF) and 15.2V for the second case (C_Q1 = C_Q2 = 22uF). The difference in the maximum is due to a change in the voltage supplied by the NI-Elvis station.

Figures 9 and 11 display the Multisim measurements of the channel connected across the red LEDs; the minimum voltage is 1.65 V, and the maximum is also 15V, while practical results of the same connection, shown in figures 15 and 16, measure the minimum to be 1.8V for the first case and 2V for the second case, only a minor change. Thus, it can be concluded that for the general behaviour, practical results follow exactly the simulation and theoretically expected results.

7. Multisim- Task B: Seat belt buzzer circuit

The seat belt buzzer circuit was constructed in Multisim as shown in Figure 17. The outputs at different stages for all possible inputs are summrized in table 1. The codes for 0s and 1s are given such that if the door is closed = 1 ➔ switch is open. If the door is open = 0 ➔ switch closed. If the seat belt is not fastened = 0 ➔ switch is closed, and if the seat belt is fastned = 1 ➔ switch is open.

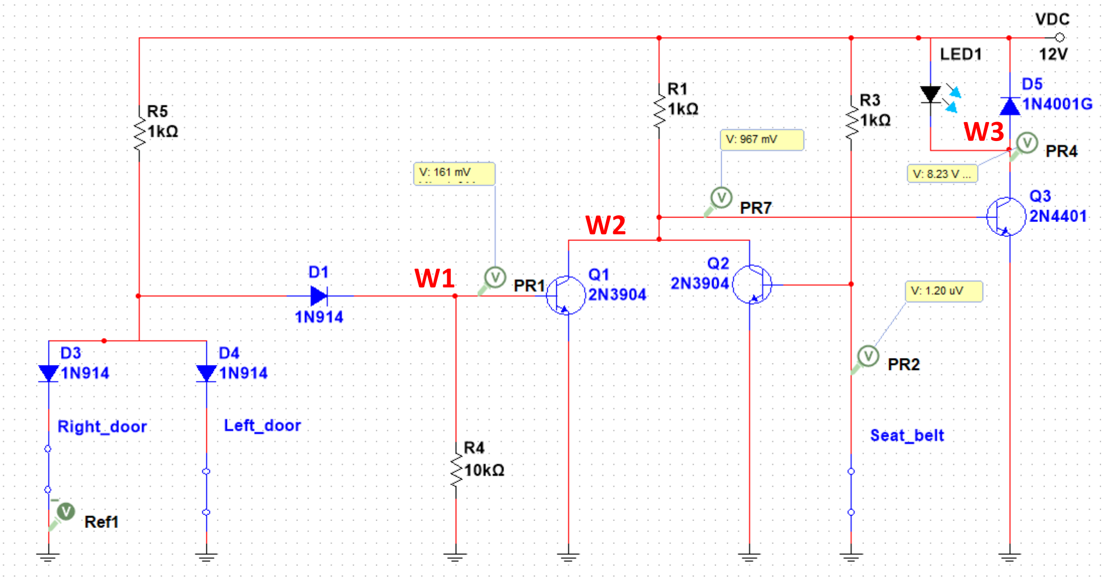

Figure 17. Seat belt buzzer circuit implemented in Multisim.

It can be observed from the table that W1 is the output of an **and-gate** with inputs of the left door and the right door. W2 is the output of a **nor-gate** with inputs of Q1 and the seat belt. W3 is an **inverter** of W2, and the buzzer (LED) state follows W2. Figure 18 gives the simplified equivalent logic circuit. Note that different interpretations of the 0s and 1s may result in different equivalent logic circuit. Figure 19 analyses the circuit with row 3 as an input, and Figure 20 analyses the circuit with row 4 as an input.

Table 2. Logic outputs for all possible inputs of figure x

Right door	Left door	Seat belt	W1	W2	W3	Buzzer
0	0	0	0	1	0	1
0	0	1	0	0	1	0
0	1	0	0	1	0	1
0	1	1	0	0	1	0
1	0	0	0	1	0	1
1	0	1	0	0	1	0
1	1	0	1	0	1	0
1	1	1	1	0	1	0

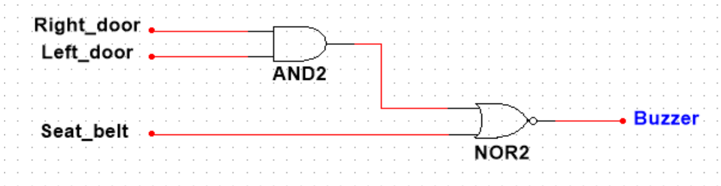

Figure 18. The equivalent logic circuit of the seat belt buzzer circuit.

Case 1: (Right door = 0, Left door = 1, Seat belt = 0)

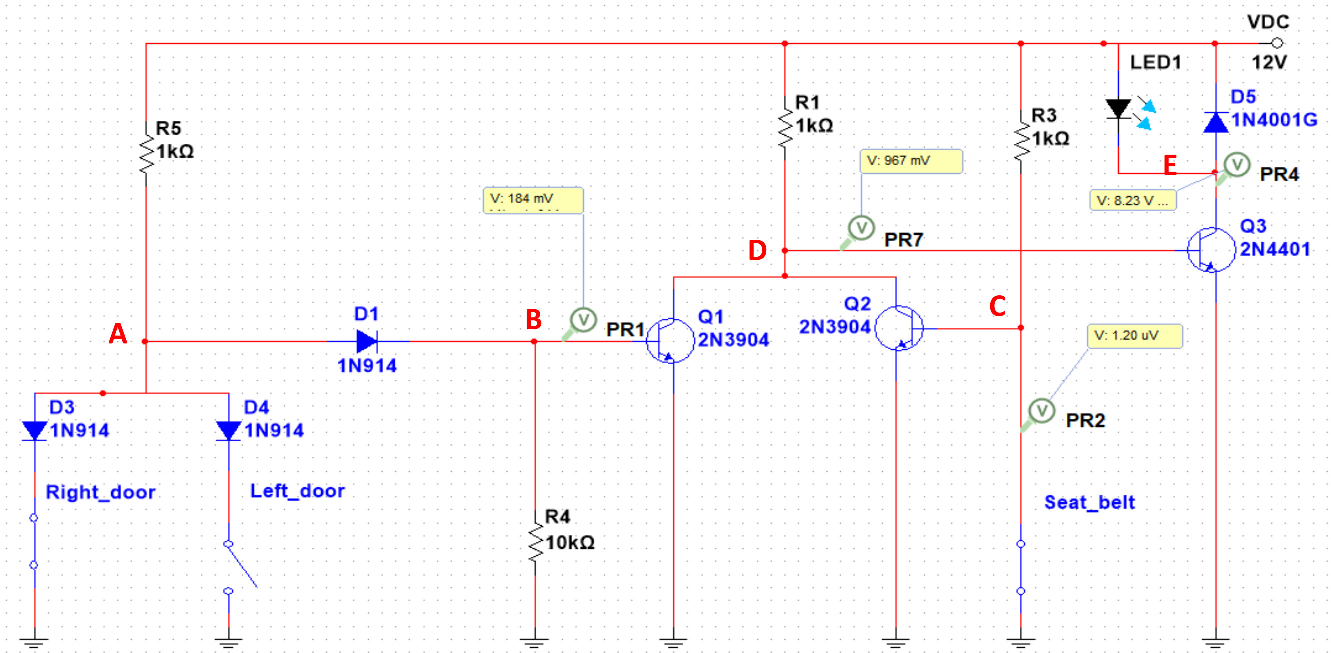

Figure 19. Seat belt buzzer circuit, with inputs Right_door = 0, Left_door = 1, and Seat_belt = 0.

As the left door switch is open, no current flows through diode D4, and is hence off. The right door switch is closed, therefore, diode D3 is on, with a voltage drop of around 0.7V, making voltage at node (A) 0.7V. Accordingly, diode D1 is on, which results in almost 0 volts at node (B), (VB = VA – VKnee_D1), and the voltage at node **B** is **LOW**.

The case discussed above analyses one possible input combination to the network of diodes and resistors, which acts as a logic **AND** gate; only if both switches are open (1,1) then the voltage at (A) is much greater than 0.7V (yet not equal to 12 V due to voltage drop across the resistor R5) and the output at node B is HIGH.

Further, the seat belt switch is closed, making voltage at node **C** almost zero, **LOW** (short circiut). The base terminals of transistors Q1 and Q2 are connected to nodes B and C (both low), respectively, making both transistors off, and the voltage at node **D** is **HIGH** (yet not equal to 12V due to the voltage drop across R1).

Because the voltage at node D is high, transistor Q3 is on, and current flows through the LED, turning it **on**. The voltage at node E is (12V – VK-blue led = 8.23V); hence, diode D5 is reverse biased and acts like an open circuit, and the blue LED is forward biased.

Assuming voltages at node **E** less than 12V is translated to logic 0 or **LOW**; then it can be observed that outputs at node E are the inverse of the inputs at node D; hence, the equivalence of the Q3 transistor is an **inverter** logic gate.

This case tests the inputs of the right door = 0 or open, the left door = 1 or closed, and the seat belt = 0 or not fastened; the resulting output is that the buzzer is **activated**.

Case 2: (Right door = 0, Left door = 1, Seat belt = 1)

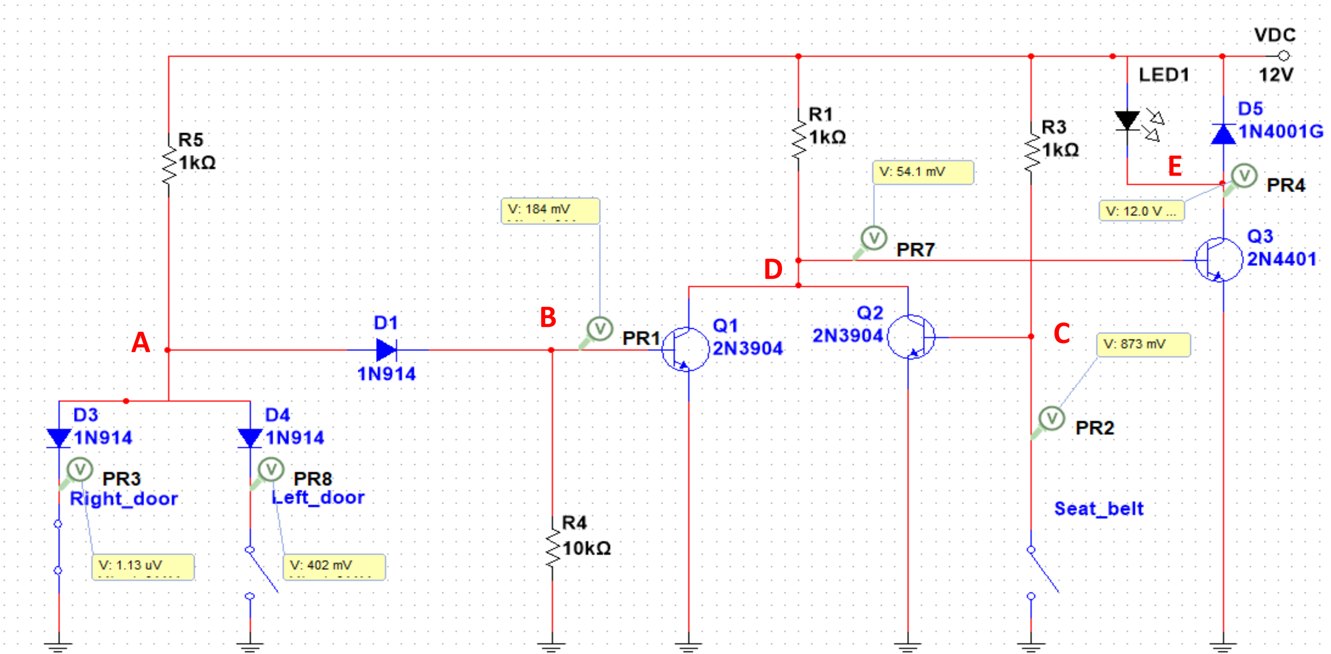

Figure 20. Seat belt buzzer circuit, with inputs Right_door = 0, Left_door = 1, and Seat_belt = 1.

As with the previous case, the left door switch is open, and no current flows through diode D4, making diode D4 off. The right door switch is closed, diode D3 is on with a voltage drop of around 0.7V, and the voltage at node (A) is 0.7V; thus, turning diode D1 on, which results in almost 0V at node (B), and voltage at **B** is **LOW**.

The seat belt switch is open, making the voltage at node **C HIGH**, yet not equal to 12V due to voltage drop across R1**.** The base terminals of transistors Q1 and Q2 are connected to nodes B and C, respectively; therefore, Q1 is off, and Q2 is on. Transistor Q2 is at saturation, acting like a short circuit, thus, short-circuiting Q1 and the voltage at node **D** is **LOW**.

The case discussed above analyses one possible input combination to the network of the two transistors (Q1 and Q2) and resistor, which acts as a logic NOR gate; only if both voltages of nodes B and C are low, then both transistors are off, and the output voltage at D is HIGH. Otherwise, if either or both node voltages are high, then either or both transistors are on, hence short-circuiting the other transistor and resulting in a **LOW** output voltage at **D**.

Moreover, because the voltage at node D is low, transistor Q3 is off (open circuit), and no current flows through the LED, turning it **off.** The voltage at node E is 12V, and diode D5 and LED with equal potentials at each terminal act like short circuits. Assuming a voltage of 12V at node **E** is a logic 1 or **HIGH**, then this confirms that transistor Q3 is an inverter of the input at D.

This case tests the inputs of the right door = 0 or open, the left door = 1 or closed, and the seat belt = 1 or fastened; the resulting output is that the buzzer is **not activated**.

8. Conclusion

In this report, a police siren light circuit was constructed by modifying an astable multivibrator circuit. Designing the circuit implements previously learned circuit analysis skills and the understanding of the working of BJTs and more knowledge gained from the course Electronic Circuits and Devices. The designed circuit was tested and analysed using the simulation software, Multisim, and experimental testing. The frequency of the astable multivibrator circuit was also studied, and the conclusion derived is that increasing the time constant of the RC network of the multivibrator circuit decreases the frequency or the flickering rates of the LEDs, and vice versa. Also, oscilloscope results observations noted from simulation and practical implementations match the expected behaviour of an astable multivibrator.