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Procedia Computer Science 183 (2021) 493–503

Procedia Computer Science

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10th International Conference of Information and Communication Technology (ICICT-2020)

The design of a vehicle detector and counter system using inductive loop technology

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Abstract

Scheduling vehicles at multiple intersections remain an issue of concern in road traffic control. Traffic lights have been widely employed in many countries, however, determining the best intersection to grant access to using the number of vehicles present as a yardstick needs to be improved on. Therefore, this article presents the design of a vehicle detector and counter system using inductive loop technology. The proposed system is majorly made up of the inductive loop section, the electronic vehicle detector section and the counter section. The inductive loop uses an electromagnetic communication to create an electric current in a nearby wire, when a vehicle crosses the loop, the inductance of the loop is increased. Based on the oscillating signal received from the inductor loop, the electronic detector section uses a voltage comparator stage and Darlington transistor arrangement to detect the vehicles on the queue. Afterwards, two up-counters and an up/down counter were used to keep track of vehicles entering and leaving the queue. The design was simulated and tested in Proteus virtual system modelling software. The simulation results obtained revealed that the design could be employed for detecting and counting vehicles at intersections so as to effectively control traffic.

Keywords: Traffic Control, inductive loop technology, vehicle detection, vehicle counter

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1877-0509
10.1016/j.procs.2021.02.089

1. Introduction

Continuous population and economic growth have led to the increase in the number of vehicles on major cities of the world. This has subjected the world to increasing congestion and pollution[1]. The 2019 INRIX global traffic scorecard reported Bogota (Columbia), Rio de Janeiro (Brazil), Rome (Italy), Paris (France) and Belo Horizonte (Brazil) to be the top 5 congested cities in the world losing 191, 190, 166, 165 and 160 hours in traffic respectively[2]. It was further estimated that congestion caused each American nearly 100 hours, $1,400 in 2019[3] while UK economy lost UK economy lost £6.9 billion in 2019[4]. This trend is seen in other major cities of the world such as Moscow, Istanbul, Mexico City, Sao Paulo, London etc. In addition to the loss of time and money, pollution via emission of carbon monoxide and noise are common characteristics of congestion. Among other solutions aimed at reducing congestion in urban centers, traffic lights have been widely employed[5,6,7,8]. They typically use red, green and yellow lights to dictate when drivers of incoming vehicles stop, proceed or move with caution. Automatic traffic control systems can be categorized into three[9]. The first category employ measurements obtained from intersections to dictate when the lights come up. They do not put traffic on the intersections into consideration but employ pre-defined traffic signal plans. For the second category, traffic light signals are based on cycle basis. Heuristic methods are employed to determine and control when the lights come up. The third category also employ heuristic methods to determine when the traffic light signals come up, nonetheless, the timing for one cycle may vary from the next. However, several issues of concerns have characterized these categories of automatic traffic control systems and several solutions have been proposed in the literature towards providing a lasting solution to these issues. Traffic light at intersections also rely on the accuracy of devices used to estimate the number of vehicles on a queue. Once a wrong estimate has been supplied, intersections with fewer vehicles could be granted right of way while intersections with long queues are ignored. Several technologies have been proposed in the literature to estimate the number of vehicles present on a queue, such include mobile sensors, Global Positioning System (GPS)[11], probe vehicle trajectories, loop detectors, magnetic sensors, travel time, video images etc. These data sources are extensively discussed in the literature review section. This article explores the use of inductive loop technology to estimate the number of vehicles on an intersection. The data retrieved is expected to be used as an input to the traffic light for granting right of way to intersections based on the chosen scheduling algorithm.

2. Related Works

Several technologies have been proposed in the literature to capture the number of vehicles on a queue. Such include radio Frequency Identification (RFID) technology[10]. RFID tag was placed on each vehicle while RFID reader placed at the intersections captured the presence and number of vehicles. However, the technique relied on the RFID tag on the vehicle and the corresponding reader on the intersections. Should any be faulty, the presence of the vehicle won't be noticed and the queue length can't be estimated. Short vehicle trajectories obtained from mobile sensors has also been employed[12]. The location, vehicle speed and timestamp were tracked using virtual loop detectors, these are Installed at the upstream and downstream section of the intersections. However, vehicles within a short range can be covered. Similarly, a solution to the long queue problem using short vehicle trajectories collected in a VTL zone from mobile sensors have also been proposed[13]. A vehicle trajectory reconstruction method was employed to recover free flow arrival traffic state from short trajectories when long queue happens. This was used to estimate the total intersection delay of the sample vehicle on the queue. Vehicle trajectory data have also been employed for queue length estimation[14]. Downstream and upstream detectors were used to generate vehicle trajectory data. VISSIM software was used for the simulation. A technique that used License Plate Recognition (LPR) data vehicle queue length estimation was also proposed[15]. LPR camera was stationed at strategic points to capture pictures of vehicles as they pass the virtual detection zone. No vehicle will be captured until it passes the virtual detection zone. Therefore, as vehicles pass the stop line, the timestamps and license plate number are recorded. These are used to estimate vehicle queue lengths. The data obtained was then reconstructed using Gaussian process interpolation model. Furthermore, A vehicle loop detector layout was employed to detect vehicle volumes[16]. The traffic data generated from the vehicle loop was then employed for the delay and queue length estimation models. A total of 16 loop detectors were employed in the design. An average prediction error of 9.09% and 8.80% were recorded for the developed vehicle delay and queue length respectively. Furthermore, magnetic sensor was also proposed for vehicle detection and queue length estimation[17]. Three queueing estimation methods (Tail interval-based Method, passing time-based Method, and Tail interval and Passing time-based Method (T-PM)) based on single sensor were then proposed. T-PM recorded the best queue length estimation in terms of accuracy and robustness. Similarly, a Bayesian approach that used probe vehicle trajectory data to estimate vehicle queue lengths have been proposed[18]. In every signal cycle, the lower and upper bounds of the queue lengths were used. The lower bounds were estimated from the trajectory data of probe vehicles joining the queue while the upper bounds were derived from data of probe vehicles that do not meet the queue. The proposed technique yielded a 100% success rate for all the simulation tested and a low mean absolute error regardless of the traffic volume. Flow-density data have also been employed for vehicle queue length prediction[19]. The technique proposed a real-time spatio-temporal traffic queue detection algorithm. The algorithm depends used traffic flow fundamentals and a statistical pattern recognition procedure to classify traffic flow phase into congested or uncongested. Other vehicle queue length data sources proposed in the literature include travel times[20,21], GPS vehicle trajectories [22, 23, 24,25], video images[26,27,28,29].

3. Methodology

The block diagram of the proposed system is as presented in Fig. 1. It is made up of three major sections which are:

(i). The inductive loop section
(ii). The electronic vehicle detector section and
(iii). The counter section

All these sections are powered by the power section.

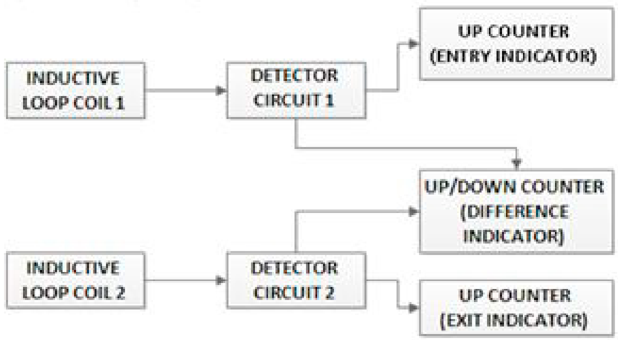

Fig. 1. Block Diagram of the Proposed Traffic Detector and Counter System.

3.1. Designing the Inductive Loop Section

The inductive loop uses an electromagnetic communication to create an electric current in a nearby wire. When a metal or vehicle crosses the loop, the inductance of the loop is increased. The proposed loop section consists of a Variable Frequency Oscillator (VFO) which is greatly influenced by the inductor L1 (the sensing coil), and a single stage transistor amplifier. The coil was constructed from a #28 AWG insulated copper coil wound for 30 turns with no core material (air-core). The output from the circuit is an oscillating signal whose amplitude can be adjusted by varying either the trimmer capacitor VC1 or the inductance of the coil L1. When constructed, the variable capacitor was adjusted to obtain a low amplitude oscillation. The signal was fed into a single stage transistor amplifier made up of transistor Q2, resistors R15 and R16, and capacitors C6 and C7 serving as input and output coupling capacitors respectively.

3.2. Designing the Electronic Vehicle Detector Section

The electronic detector section is made up of a voltage comparator stage and Darlington transistor arrangement at the output which is used to switch a relay. When the oscillating signal from the loop section stage arrives, it is detected (rectified) by the diode D1 so that it assumes a dc value that can be compared with a reference voltage set by the potential divider resistors R17 and RV1 at the inverting input (pin2) of the comparator IC, U10: A (LM393). When there is no detection at the loop section, the reference voltage will be greater so that the output of the comparator will be a LOW signal (0V) having no effect on the relay. However, as the signal from the loop section rises due to the proximity of a metallic object, voltage at pin 3 of the comparator rises above the reference so that the comparator's output goes HIGH (+12V). Consequently, the output transistors are turned-on and the relay coil is energized. In turn, a LOW (0V) signal is transferred to the respective counter sections for counting and display.

3.3. Designing the Counter Section

Three counter / display circuits were proposed; two identical (up-counters) that indicate digit count for the entry loop and the exit loop and a third counter (up/down counter) which is fed from each detector ends such that it generates a difference count relative to the other two counters.

3.3.1. Entry/Exit Loop Counter

The counter section for the entry and exit detector comprise of a seven-segment display decade counter IC CD4026. This chip is a dual action IC consisting internally of a decade counter and a display drive. The counter contains a set of contact connections representing the relay contacts of the entry detector. The lower contact labelled Q is connected to the input of an inverter gate IC, U9: A (CD4026) whose output is connected to the clock input pin (1) of U1. The carry-out pin (5) of U1 is connected to the clock input of U2 so that on every tenth count of U1, counter U2 is incremented by 1. This way, the whole arrangement forms a 2-digit counter. When the entry detector is activated, the relay contacts close thereby grounding terminal Q so that a negative-going signal arrives at the input of the inverter gate. The signal changes phase (becomes a positive-going signal) at the output of the gate and then triggers U1. This circuit of the entry loop will always count upwards from 0 to 99 reflecting the number of times that the entry detector is activated. The exit counter circuit is exactly identical in configuration and operation to the entry counter except for an extra contact/ terminal 'P' linked to some parts of the difference counter. Just like the entry circuit, the counter also counts up (0 to 99) and the displayed digits represent the number of vehicles that are detected leaving the count zone.

3.3.2. The Difference Counter

The difference counter is made up of two cascaded sections of counter (CD4510) and decoder (CD4511) ICs. The counter IC is a CMOS BCD up/down counter that is capable of counting up from 0 to 9 as well as in the reverse direction counting down from 9 to 0 depending on the nature of the pulse input at its clock terminal, pin 15. Pin10 of the IC is held at high potential (+5V) to count 'up' while it is held at ground potential (0V) to count 'down'. The 'carry-out' terminal of counter U7 connects to the clock input of counter U8 so that the two counters act as a single 2-digit unit. When the relay of the entry (first) detector is activated, a negative-going signal appears at terminal Q of the relay. This signal feeds through the inverter gate IC, U9: A to become a positive-going pulse that triggers the counter U7. Since the counter's up/down pin is held at positive potential via resistor R14, the counter increments (counts up) and the corresponding digit appears on the seven-segment display output. This happens every time the input detector is activated. On the other hand, when the exit (second) detector is activated, a similar action described above takes place except that in this case the up/down terminal is momentarily held at ground potential since it is connected to Terminal-P of the second relay. Consequently, the counter decrements in count and the change is reflected on the output display unit(s). In this way, the counter counts down every time the exit detector is activated.

3.4. Designing the Power Section

The needed voltage will be supplied to the various components of the system using the power section. The power supply was divided into regulated and unregulated categories.

3.4.1. The Unregulated Power Supply

This has a step-down transformer that is rated 220V/15V and a maximum rms current of 1A. in addition to the transformer, a SV4B bridge rectifier was also used. It has a peak reverse voltage of 1000V and a forward rectified current of 2A. The output dc voltage Vp was achieved using equation 1 such that:

$$Vp = (Vrms \times \sqrt{2}) - 1.40V \quad (1)$$

Where Vp is the maximum dc voltage that can be obtained after rectification and proper filtering, Vrms is the root-mean-square transformer output voltage (15V), √2 is the conversion factor from RMS to Peak voltage. The sum of voltage drop across 2 series diodes during each half cycle of rectification is taken to be 1.40V. Therefore, $Vp = 15\sqrt{2} - 1.40 = 19.81V$. However, to attain this value, it is essential to select the right value of filter capacitor so that the ripple voltage present in the output dc can be reduced to a minimum. Standard practice recommends that the peak-to-peak ripple voltage should not exceed 2Vp-p hence that will be our working value. The filter capacitor was calculated using equation 2, such that:

$$Cf = I / (f\ Vr) \quad (2)$$

Where I = maximum load current, in this case taken as transformer rated output current (1A), f is the output signal frequency '2fin 'which is 100Hz for full-wave rectifiers. Vr is the maximum allowable peak-to-peak ripple voltage 2Vp-p. Therefore, Cf = 1A / (100Hz X 2V) = 0.005F = 5000µF. However, a value of 4700µF is the closest commercially available value.

3.4.2. The Unregulated Power Supply

The regulated DC power supply has two different fixed voltage regulator ICs: LM7805 and LM7812. The LM7805 produces a constant +5V dc supply at 1A maximum while the LM7812 produces a +12V dc output also at 1A maximum. Capacitors C2 – C5 are ceramic / polyester type and are referred to as bypass capacitors. Their function is to bypass to ground, glitches and voltage spikes which may be present on the supply line and can cause erratic operation of electronic circuits. By standard, 10nF – 100nF is the recommended range.

4. Design Analysis and Output Discussion

The proposed traffic detector and counter system consists of two inductive loop coils, two detector circuits, two up counters and an up/down counter. The inductive loop coils and detector circuits were used to keep track of the number of vehicles entering and leaving each intersection. The numbers of vehicles counted will be displayed on the respective up counters. Also, there is a counter dedicated to count the number of vehicles that remained on each intersection. This is the difference between the number of vehicles that entered the intersection and the number of vehicles that left.

4.1. The Designed Power Supply Section

The power supply section was designed to supply voltage to the whole system. It is made up of the unregulated and the regulated DC supply.

4.1.1. The Unregulated DC Power Supply

As shown in Fig. 2, the unregulated DC power supply is made up of a 220V/15V step-down transformer and a maximum rms current of 1A. It also uses a SV4B bridge rectifier with a peak reverse voltage of 1000V and a forward rectified current of 2A. The output of this section is fed into the regulated power section.

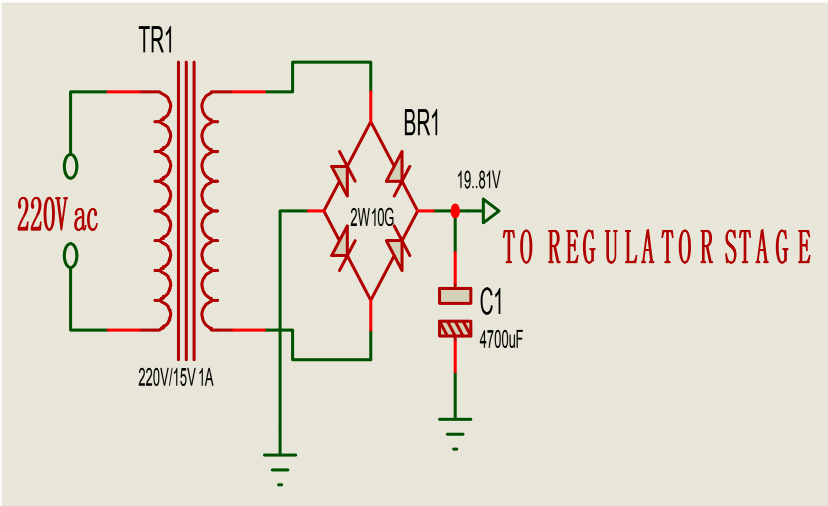

Fig. 2. The Unregulated Power Supply Design

4.1.2. The Regulated DC Power Supply

The design of the regulated DC power supply is shown in Fig. 3. Voltage regulator ICs LM7805 and LM7812 were used to produce a +5V and =12V dc supply respectively. Capacitors C2 – C5 were used to ground glitches and voltage spikes which may be present on the supply line.

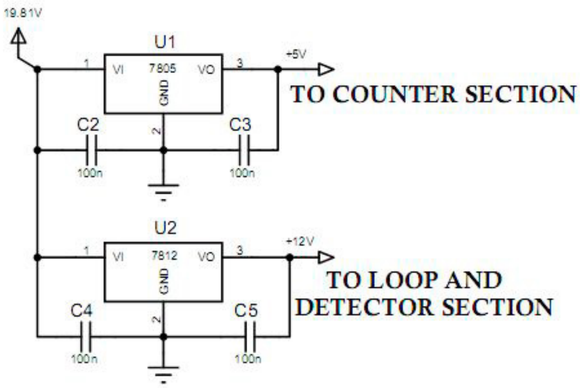

Fig. 3. Regulated Supply Stage

4.2. The Designed Inductive Loop Section

The complete design of the inductive loop section is shown in Fig. 4. When a metallic object is placed close to the coil, its inductance as well as its amplitude will increase. One of this circuit was used at the first vehicle entry point while the second was used at the exit point.

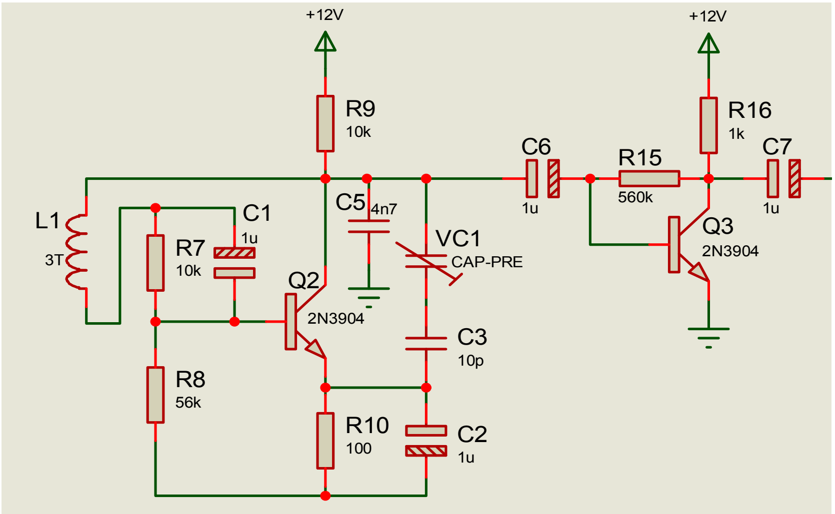

Fig. 4. Loop sensor circuit using a Variable Frequency Oscillator

The trimmer capacitor VC1 or the inductance of the coil L1 was used to adjust the amplitude of the oscillating signal generated in this section. The signal was later passed into a single stage transistor amplifier that consist of transistor Q2, resistors R15 and R16. Capacitors C6 and C7 serve as input and output coupling capacitors respectively.

4.3. The Designed Electronic Detector Section

The output signal from the loop section was used to activate the electronic detector section shown in Fig. 5. The signal from the loop section was rectified by diode D1 so as to be able to compare the output voltage with a reference voltage set by resistors R17 and RV1. However, when a vehicle is closer, the voltage of pin 3 rises above the reference voltage then the output transistors are turned-on and the relay coil is energized. Afterwards, a low (0V) signal is transferred to the counter sections for counting and display. Two of this circuit was used, one for the first (ENTRY) loop section and the other for the second (EXIT) loop section. The entire process of this stage is captured in the schematic diagram in Fig. 5.

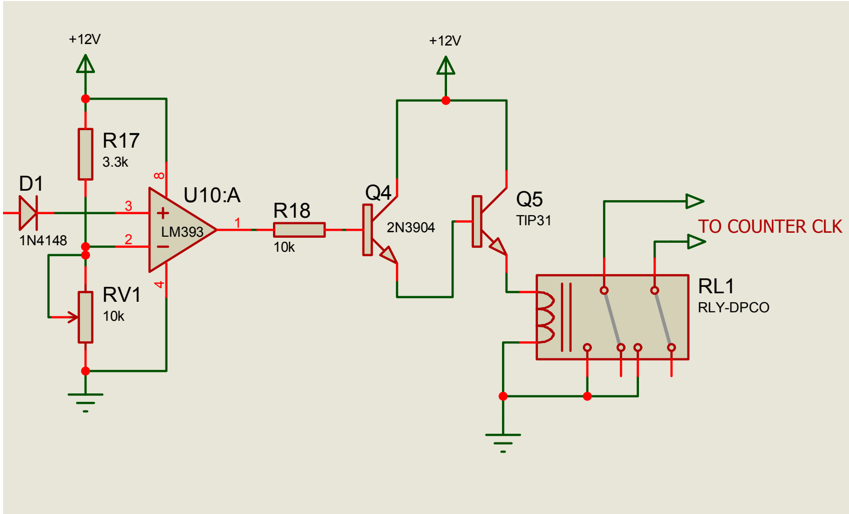

Fig. 5. The Electronic Detector Circuit showing the Signaling Relay

4.4. The Designed Counter Section

This counter section is made up of the entry counter, the exit counter and the difference counter.

4.4.1. Entry/Exit Loop Counter

The entry/exit loop is used to count the number of vehicles entering and leaving the intersection. it is connected to a display unit that will project the number of vehicles entering and leaving the intersection display. The schematic diagram for the entry loop is shown in Fig. 6 while the design for the exit loop is shown in Fig. 7.

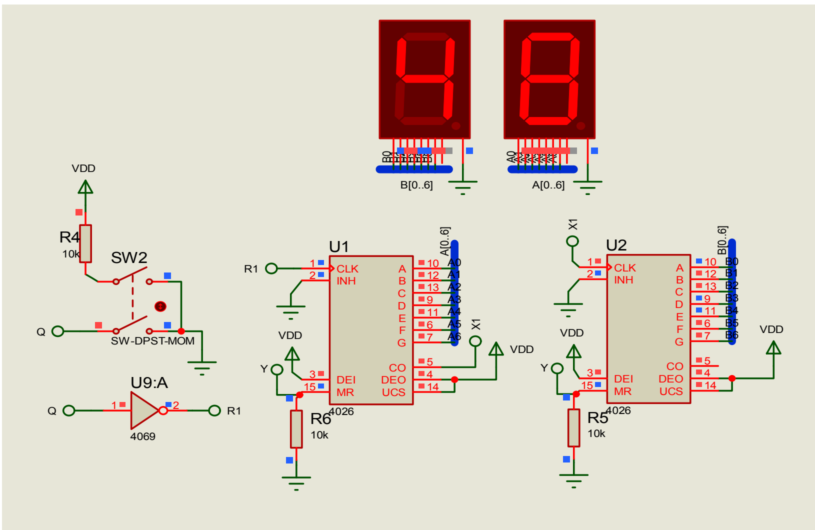

Fig. 6. The ENTRY Counter Displaying a Count of 48

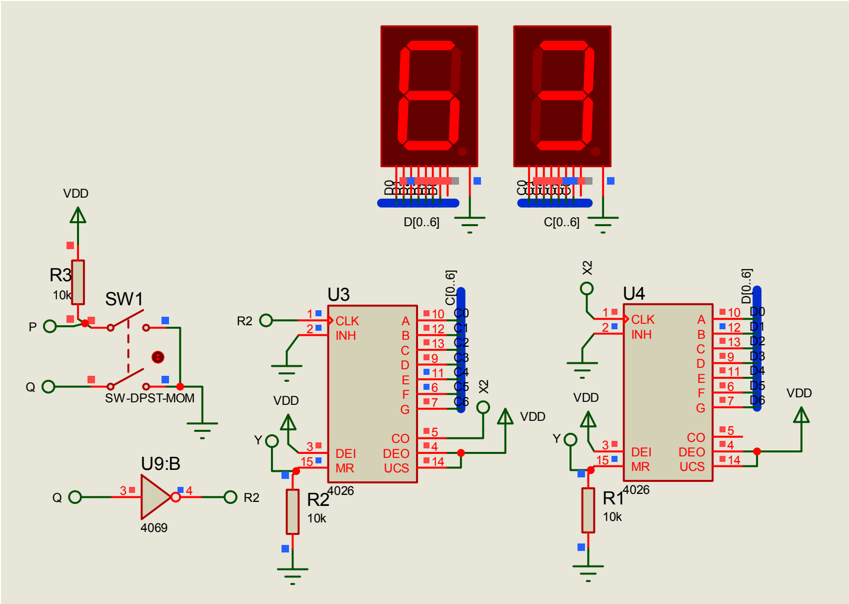

Fig. 7. The EXIT Counter Displaying a Count of 63.

4.4.2. Difference Counter

The difference counter was used to keep track of the difference between the number of vehicles entering and leaving the intersection. The value displayed on the entry counter is expected to be higher than that displayed on the exit counter, therefore, it is not expected that the difference counter will display a negative value at any point in time. The designed difference counter is shown in Fig. 8.

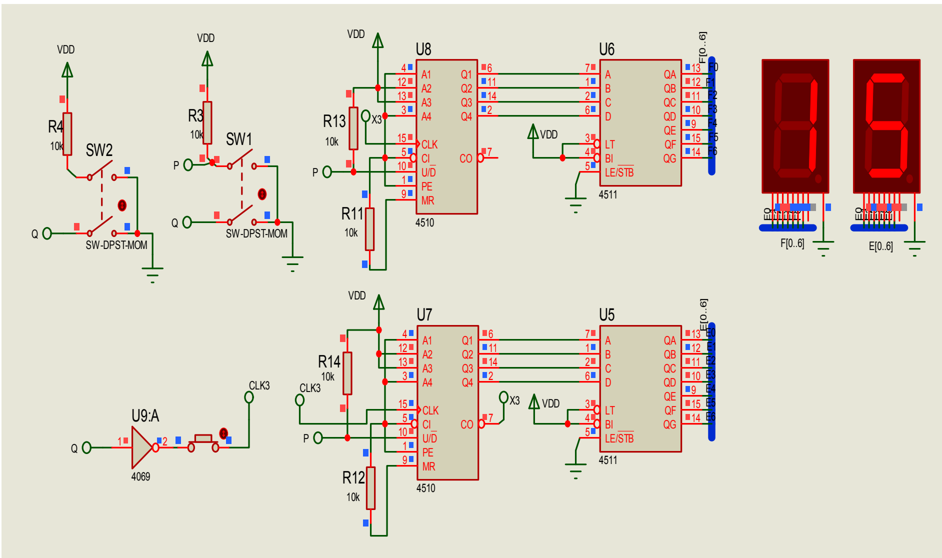

Fig. 8. The Difference Counter Displaying a 'Difference' Count of 15

4.5. The Complete Schematic Diagram

The complete schematic diagram of the entire system is presented in Fig. 9. It shows the interconnections among all the various sections of the system. Proteus virtual system modelling software was used to draw and test the digital circuits. When the drawing of the schematic was completed, appropriate simulation commands were initiated and the design was observed to operate correctly; both the entry and exit counters indicated respective increase counts while the difference counter reflected the difference of the other two counters.

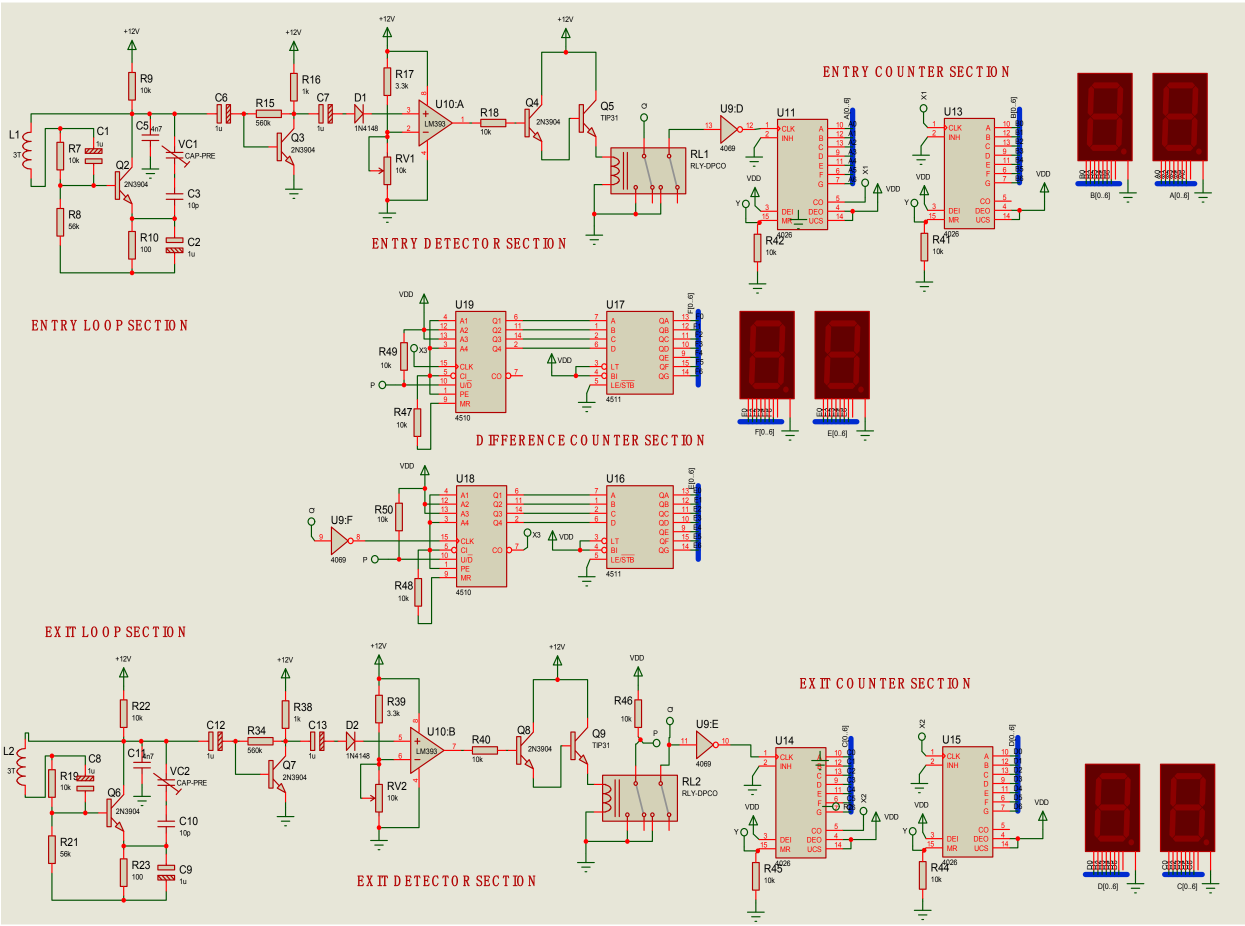

Fig. 9. Complete Schematic diagram of the Traffic Detector and Counter System.

5. Conclusion

The accuracy and reliability of traffic light signals depends on the effectiveness of the technology used to count vehicles available on the queue. To a large extent, it's accuracy still depends on the vehicle length estimation algorithm employed. However, this article has discussed in details, the design of a vehicle detector and counter system using inductive loop technology. The system is made up of a power section, the inductive loop section, the electronic detector section and a counter section. the design and testing were carried out in a Proteus simulation software. Each section of the system was tested before the system was tested as a whole. The several commands issued and the various values displayed on the counter showed that the design was perfect.

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