INTELLIGENT TRAFFIC CONTROL SYSTEM USING FIBER OPTIC SENSOR

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CERTIFICATE

This is to certify that the work entitled, **"Intelligent traffic control system using fiber optic sensor"** submitted by **Himanshu Shekhar, Chetan Negi, Anupam Garg and Abhishek Gupta** in partial fulfillment for the award degree of Bachelor of Technology in Electronics and Communications of Jaypee University of Information Technology has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

Sarit Pal
(Sarit Pal)

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ABSTRACT

The main object of this study was to design and implement a suitable algorithm and simulation for an intelligent traffic signal control system. The system developed is able to sense the presence or absence of vehicles within certain range by setting the appropriate duration for the traffic signals to react accordingly. The system helps to solve the problem of traffic congestion by following lane selection and tie breaker algorithms. The simulation of the algorithm of the traffic signal system was done using ModelSim Se 6.1d software. The new timing scheme that was implemented promises an improvement in the current traffic light system and this system is feasible, affordable and ready to be implemented especially during peak hours. The algorithm has been tested with some arbitrary values for the number of vehicles and yielded satisfactory results.

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INTRODUCTION

Driving is a privilege that most adults today have. However, driving can also be very dangerous and in some cases, deadly. In busy areas such as urban cities or suburban neighborhoods, traffic lights have been implemented to encourage drivers to pay attention and be courteous to allow other people through intersections. The basic premise of traffic lights is fairly simple: green means go ahead, yellow means please slow down and red means stop.

Traffic signals must be instructed when to change phase. They can also be coordinated so that the phase changes called for occur in some relationship with nearby signals.

1.1 Current traffic control system

The concept of traffic lights used in India is that they are based on a timer system. Once one directional light turns yellow, it warns other cars to prepare to stop, and then when it turns red, the opposite traffic light then turns green, allow oncoming traffic to pass through. Fixed amount of time is allocated to red as well as green lights, irrespective of the amount of traffic present on a particular intersection. Each phase of the signal lasts for a specific duration before the next phase occurs; this pattern repeats itself regardless of traffic. Timer-based signals are effective in one way grids where it is often possible to coordinate the traffic lights to the posted speed limit. They are however quite disadvantageous when the signal timing of an intersection would profit from being adapted to the dominant flows changing over the time of the day. Thus, they lack dynamism in their mode of operation.

1.2 Need for an intelligent traffic control system

Traffic jams are a very common problem in metros. Blame should not only be given to lack or inadequate number of flyovers but also to the inadequate working of the traffic control systems. There are two main reasons which lead to accumulation of traffic which are as follows:

1. **Long duration green signal in an empty lane:** This only leads to wastage of time of those drivers who are in other lanes. Besides, it does not serve any purpose on the empty lane. Although it may allow passage of a few vehicles during its green signal duration but this occurs at the cost of accumulation of traffic at other lanes.

2. **Long duration red signal in a very busy lane:** Since the traffic control system is completely timer based, it stops the traffic in a busy lane for more than necessary time duration. Usually, the duration of green signal is not sufficient so that the entire traffic can pass through the intersection. Thus, it again leads to accumulation of traffic in that lane eventually leading to a traffic jam.

Generally, only 2 lanes are busy in a 4-lane crossing. Thus, giving equal weightage to all 4 lanes is not a good option. There is an urgent need for an intelligent traffic control system which can identify the busy lanes. The main aim in designing and developing of the Intelligent Traffic Signal Simulator is to reduce the waiting time of each lane of the cars and also to maximize the total number of cars that can cross an intersection by following an adequate algorithm to calculate the waiting time

As mentioned above, current traffic light systems operate on a timing mechanism that changes the lights after a given interval. An intelligent traffic light system should sense the presence or absence of vehicles and react accordingly. The idea behind intelligent traffic systems is that drivers will not spend unnecessary time waiting for the traffic lights to change. An intelligent traffic system detects traffic in many different ways.

The new traffic systems should react to motion to trigger the light changes. Once the sensor picks up the presence of a car, a switch causes the lights to change. In order to accomplish this, algorithms are used to govern the actions of the traffic system. While there are many different programming languages today, some programming concepts are universal in Boolean Logic.

Any change in traffic rules or in traffic control system should be notified to the general masses as soon as possible. It is because people need to understand the function of traffic signals so that they can improve driving habits by controlling the speed in order to reduce the number of associated traffic accidents. The more number of drivers who know about the operation of traffic signals, the less frustrated they are going to be while waiting for the lights to change. Awareness among people is necessary for the success of the new traffic control system.

1.3 Turning signals and rules

Depending on the jurisdiction, traffic may turn after stopping on a red (right in right-driving countries; left in left-driving countries), provided they yield to pedestrians and other vehicles. Our country follows the right driving pattern. Most jurisdictions allow turning on red in the opposite direction (i.e. left in right-driving countries; right in left-driving countries) from a one-way/two-way road onto another one-way/two-way road. Our model assumes that this jurisdiction is allowed at every intersection. India's traffic control systems have dedicated signals for turning across the flow of opposing traffic. Such signals are called dedicated right-turn lights (since opposing traffic is on the right). Thus, traffic cannot turn in the right direction unless this light is not on. Our model is based on a 4-way crossing and not on a T-way crossing. Thus, 4 traffic lights are needed at each lane.

Apart from the traffic lights, appropriate sensors must be chosen in each of these lanes. It is because of these sensors only that the vehicles can be counted. Thus, sensors form a very essential part of the entire system. Defects in other components such as control box and traffic lights can be corrected very easily. But changes in sensors can take a long time. Therefore, it is essential to choose a highly reliable, cost efficient and robust sensor for the successful functioning of the intelligent traffic control system.

2

BRIEF RESUME OF THE EXISTING SENSING TECHNIQUES

2.1 Introduction

Sensors used for vehicle detection and surveillance may be described as containing three components, the transducer, a signal processing device, and a data processing device. The transducer detects the passage or presence of a vehicle or its axles. The signal-processing device typically converts the transducer output into an electrical signal. The data processing device usually consists of computer hardware and firmware that converts the electrical signal into traffic parameters. Typical traffic parameters include vehicle presence, count, speed, class, gap, headway, occupancy, and weight and link travel time. The data processing device may be a part of the sensor, as with devices that produce serial output data, or may be controllers external to the sensor as utilized with sensors that have optically isolated semiconductor or relay outputs.

Sensors can be classified as **in-roadway sensors** and **over-roadways sensors.**

An in-roadway sensor is one that is either

- Embedded in the pavement of the roadway.
- Embedded in the sub grade of the roadway.
- Taped or otherwise attached to the surface of the roadway.

Examples of in-roadway sensors include inductive loop detectors, which are saw cut into the pavement; weigh-in-motion sensors, which are embedded in the pavement; magnetometers, which may be placed underneath a paved roadway or bridge structure.

An over-roadway sensor is one that is mounted above the surface of the roadway either

- Above the roadway itself.
- Alongside the roadway, offset from the nearest traffic lane by some distance.

Examples of over-roadway sensors are video image processors that utilize cameras mounted on tall poles adjacent to the roadway or traffic signal mast arms over the roadway; microwave radar, ultrasonic, and passive infrared sensors mounted in a similar manner; and laser radar sensors mounted on structures that span the lanes to be monitored.

2.2 In-roadway sensor technologies

2.2.1 *Fiber optic sensors*

Fiber optic sensors utilize some of the measurable properties of light such as optical power or intensity, and the phase and polarization of the light wave to measure desired parameters such as temperature, pressure, strain, etc. Usually, power must be measured as a function of other parameters, such as time, position, and wavelength. Typically, a laser supplies the light source that could be directed over short or long distances in free space to a receiver. The light is transmitted through long lengths of hair-like fused silica fibers.

Principle of operation

Light is conducted down the length of the fiber by similar but multiple internal reflections. In fibers, light is reflected from the cladding (lower index material) back into the core. In this manner it continues to propagate forward, through continual reflection. The key components of a fiber optic sensor include: optical fiber, light source, optical detector, and optical modulator. Optical fibers are used to sense the environmental signal in two distinct ways. One method is typically referred to as extrinsic and the other as intrinsic.

In the extrinsic case an optical fiber leads up to a "black box" which impresses information onto the light beam in response to an environmental effect. The information could be impressed in terms of intensity, phase, frequency, polarization, spectral content, or other methods. An optical fiber then carries the light with the environmentally impressed information back to an optical and/or electronic processor.

The intrinsic or all fiber sensor uses an optical fiber to carry the light beam and the environmental effect impresses information onto the light beam while it is in the fiber.

Intrinsic fiber optic sensors can be more sensitive since the environmental signal is directly impressing information onto the light beam.

Advantages

Fiber optic sensors in traffic monitoring applications offer the potential of providing counting, speed, classification, while offering sensors that are light weight, immune to electromagnetic interferences, offer the ability to be embedded under hostile environments, and have extremely high bandwidth capability. Furthermore, it is anticipated that traffic monitoring systems that utilize fiber optic sensors, once developed, will eventually be lower in overall cost relative to conventional systems, due to the inherently low cost of the fiber optic sensors.

Disadvantages

The major disadvantage of traffic monitoring systems that use fiber optic sensors is that the technology is immature. There are only a handful of these types of sensor systems commercially available for counting, speed, and classification applications. Another obvious disadvantage of fiber optic sensors in traffic monitoring applications is the potential for breaking of the fiber in intrinsic sensors due to its delicate structure when a load is applied to it such as from a vehicle crossing over it.

2.2.2 Magnetic sensors

Principle of operation

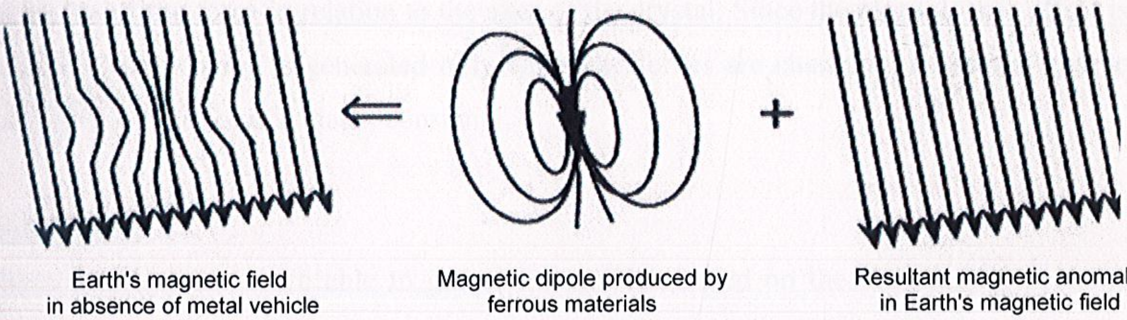
Magnetic sensors are passive devices that indicate the presence of a metallic object by detecting the perturbation (known as a magnetic anomaly) in the Earth's magnetic field created by the object. Figure 2.1 shows the magnetic anomaly produced by the magnetic dipoles, i.e., magnetic fields, on a steel vehicle when it enters the magnetometer's detection zone. The upper part of the figure indicates how the vector addition of the dipole magnetic field and the Earth's quiescent magnetic field produces the magnetic anomaly. The lower portion of the figure depicts several dipoles on a vehicle and their effect on sensor output.

Advantages

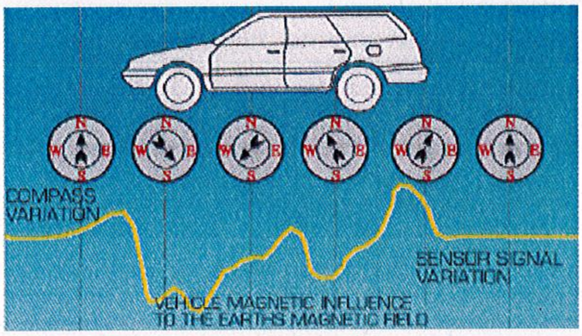
The two-axis fluxgate magnetometer along with the induction or search coil magnetometer is less susceptible to stresses of traffic as compared with others. Also some models of the two-axis fluxgate magnetometer transmit data over wireless RF link. The induction magnetometer can be used where others are not feasible (e.g., bridge decks) and some models can be installed under the roadway without the need for pavement cuts.

Disadvantages

Installation of magnetic sensors requires pavement cut, coring, or tunneling under the roadway and thus requires lane closure during installation. Magnetic detectors cannot generally detect stopped vehicles. Also, some models have small detection zones.



(a) Magnetic anomaly induced in the Earth's magnetic field by a magnetic dipole



(b) Perturbation of Earth's magnetic field by a ferrous metal vehicle.

Figure2.1 Magnetic anomaly in the earth's magnetic field induced by magnetic dipoles in a ferrous metal vehicle.

2.2.3 Piezoelectric sensors

Piezoelectric material converts kinetic energy to electrical energy. Some polymers exhibit these properties to a high degree and it is these types of materials that are ideal to use in the construction of piezoelectric sensors.

Principle of operation

Piezoelectric materials generate a voltage when subjected to mechanical impact or vibration. Electrical charges of opposite polarity appear at the in and outer faces of the material and induce a voltage. The measured voltage is proportional to the force or weight of the vehicle. The magnitude of the piezoelectric effect depends upon the direction of the force in relation to the axes of the crystal. Since the piezoelectric effect is dynamic, i.e., charge is generated only when the forces are changing, the initial charge will decay if the force remains constant.

Advantages

Piezoelectric sensors are able to gather information based on the tire passing over the sensor, thus creating an analogue signal that is proportional to the pressure exerted on the sensor. This property of piezoelectric sensors allows them to differentiate individual axles with extreme precision. In addition, on an installed cost basis, they are only marginally more expensive than its counterpart, but provide more information in the form of improved speed accuracy, the ability to determine the classification of the vehicle based on weight and axle spacing, and the capability to determine and monitor the weights of vehicles for WIM systems.

Disadvantages

The drawbacks to the use of piezoelectric tube or cable sensors is that they include disruption of traffic for installation and repair, failures associated with installations in poor road surfaces and wear, and use of substandard installation procedures. In many instances multiple detectors are required to instrument a location. In addition, resurfacing of roadways and utility repair can create the need to reinstall these types of sensors.

Piezoelectric sensors have been known to be sensitive to pavement temperature and vehicle speed.

2.3 Over-roadway sensor technologies

2.3.1 Video image processor

Video cameras were introduced to traffic management for roadway surveillance because of their ability to transmit closed circuit television imagery to a human operator for interpretation. Present-day traffic management applications use video image processing to automatically analyze the scene of interest and extract information for traffic surveillance and control. A video image processor (VIP) system typically consists of one or more cameras, a microprocessor-based computer for digitizing and processing the imagery, and software for interpreting the images and converting them into traffic flow data.

Principle of Operation

Video image processor systems detect vehicles by analyzing the imagery from a traffic scene to determine changes between successive frames. The image processing algorithms that analyze black and white imagery examine the variation of gray levels in groups of pixels contained in the video frames. The algorithms are designed to remove gray level variations in the image background caused by weather conditions, shadows, and daytime or nighttime artifacts and retain objects identified as automobiles, trucks, motorcycles, and bicycles. Traffic flow parameters are calculated by analyzing successive video frames. Color imagery can also be exploited to obtain traffic flow data. The improved resolution of color cameras and their ability to operate at low light levels is making this approach more viable.

Advantages

VIP signal processing is continually improving its ability to recognize artifacts produced by shadows, illumination changes, reflections, inclement weather, and camera motion from wind or vehicle-induced vibration. However, artifacts persist and the user should evaluate VIP performance under the above conditions and other local conditions that may exist.

Disadvantages

Some disadvantages of the video image processor include its vulnerability to viewing obstructions; inclement weather; shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; water; salt grime; icicles; and cobwebs on camera lens that can affect performance. Also, some models are susceptible to camera motion caused by strong winds. Furthermore, the installation of a video image processor requires 50 to 60-feet mounting height (in a side mounting configuration) for optimum presence detection and speed measurement. A video image processor arrangement is generally cost effective only if many detection zones are required within the field of view of the camera.

2.3.2 Microwave radar

The word radar was derived from the functions that it performs: *RA*dio *D*etection *A*nd *R*anging. The term microwave refers to the wavelength of the transmitted energy, usually between 1 and 30 cm. This corresponds to a frequency range of 1 GHz to 30 GHz. Microwave sensors designed for roadside traffic data collection and monitoring are limited by FCC regulations to operating frequency bands near 10.5, 24.0, and 34.0 GHz. These requirements, as well as others that restrict the transmitted power, are satisfied by the sensor manufacturers.

Principle of operation

As shown in Figure 2.2, roadside-mounted microwave radars transmit energy toward an area of the roadway from an overhead antenna. The area in which the radar energy is transmitted is controlled by the size and the distribution of energy across the aperture of the antenna. The manufacturer usually establishes the design constraints. When a vehicle passes through the antenna beam, a portion of the transmitted energy is reflected back towards the antenna. The energy then enters a receiver where the detection is made and vehicle data, such as volume, speed, occupancy, and length, are calculated.

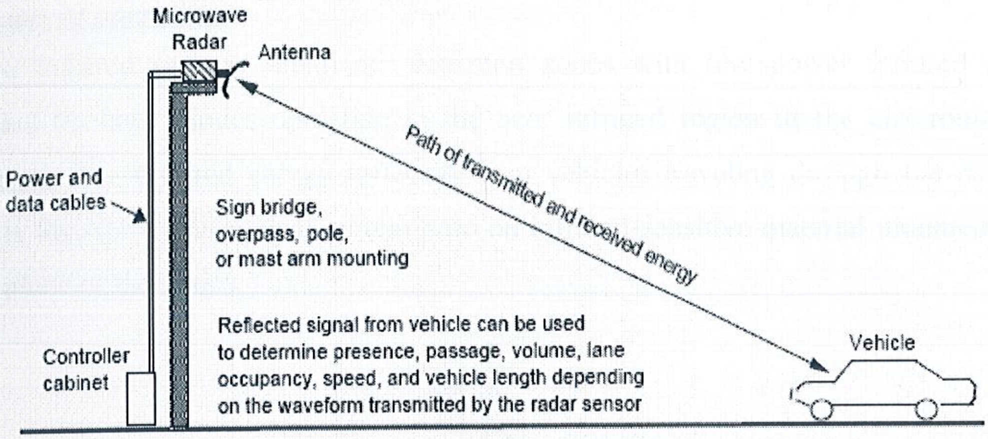


Figure 2.2. Microwave radar operation.

Advantages

An important advantage of microwave radar is that it is insensitive to inclement weather, especially over the relatively short ranges encountered in traffic management applications. Microwave radar provides a direct measurement of speed. Also, multiple lane operation models are available.

Disadvantages

CW Doppler radar sensors cannot detect stopped vehicles unless equipped with an auxiliary sensor. CW Doppler microwave sensors have been found to perform poorly at intersection locations as volume counters.

2.3.3 Infrared sensors

Active and *passive* infrared sensors are manufactured for traffic applications. The sensors are mounted overhead to view approaching or departing traffic or traffic from a side-looking configuration. Infrared sensors are used for signal control; volume, speed, and class measurement, as well as detecting pedestrians in crosswalks. With infrared sensors, the word detector takes on another meaning, namely the light-sensitive element that converts the reflected or emitted energy into electrical signals. Real-time signal processing is used to analyze the received signals for the presence of a vehicle.

2.3.3.1 Active infrared sensor

Principle of operation

Active infrared sensors illuminate detection zones with low power infrared energy supplied by laser diodes operating in the near infrared region of the electromagnetic spectrum. The infrared energy reflected from vehicles traveling through the detection zone is focused by an optical system onto an infrared-sensitive material mounted at the focal plane of the optics.

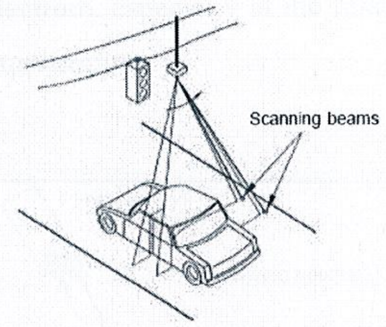


Figure 2.3. Laser radar beam geometry.

2.3.3.2 Passive infrared sensors

Passive sensors detect the energy that is emitted from vehicles, road surfaces, other objects in their field of view, and from the atmosphere, but they transmit no energy of their own. Non-imaging passive infrared sensors used in traffic management applications contain one or several (typically not more than five) energy-sensitive detector elements on the focal plane that gather energy from the entire scene. The detector in a non-imaging sensor generally has a large instantaneous field of view.

Principle of operation

Passive infrared sensors with a single-detection zone, measure volume, lane occupancy, and passage. The source of the energy detected by passive sensors is graybody emission due to the non-zero surface temperature of emissive objects. When a vehicle enters the sensor's field of view, the change in emitted energy is used to detect the vehicle as illustrated in Figure 2.4. A vehicle entering the sensor's field of view generates a signal that is proportional to the product of an emissivity difference term and a temperature difference term when the surface temperatures of the vehicle and road are equal. The emissivity term is equal to the difference between the road and the vehicle emissivities. The temperature term is equal to the difference between the absolute temperature of the road surface and the temperature contributed by atmospheric, cosmic, and galactic emission. On overcast, high humidity, and rainy days, the sky temperature is larger than on clear days and the signal produced by a passing vehicle decreases. This, in itself, may not pose a problem to a properly designed passive infrared sensor operating at the longer wavelengths of the infrared spectrum, especially at the relatively short operating ranges typical of traffic management applications.

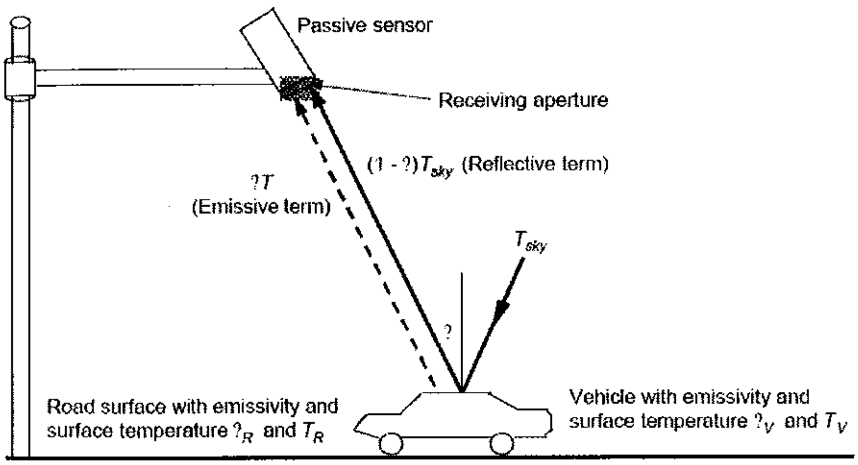


Figure 2.4 Emission and reflection of energy by vehicle and road surface.

Advantages

Installation of infrared sensors does not require an invasive pavement procedure. Some advantages of active infrared sensors are that they transmit multiple beams for accurate measurement of vehicle position, speed and class. Also, multi-zone passive infrared sensors measure speed. Multiple lane presence detection is available in side-looking models.

Disadvantages

Several disadvantages of infrared sensors are sometimes cited. Glint from sunlight may cause unwanted and confusing signals. Atmospheric particulates and inclement weather can scatter or absorb energy that would otherwise reach the focal plane. The scattering and absorption effects are sensitive to water concentrations in fog, haze, rain, and snow as well as to other obscurants such as smoke and dust. At the relatively short operating ranges encountered by infrared sensors in traffic management applications, these concerns may not be significant. However, some performance degradation in rain, freezing rain, and snow has been reported .

2.3.4 Ultrasonic sensors

Principle of operation

Ultrasonic sensors transmit pressure waves of sound energy at a frequency between 25 and 50 KHz, which are above the human audible range. Most ultrasonic sensors operate with pulse waveforms and provide vehicle count, presence, and occupancy information. Pulse waveforms measure distances to the road surface and vehicle surface by detecting the portion of the transmitted energy that is reflected towards the sensor from an area defined by the transmitter's beamwidth. When a distance other than that to the background road surface is measured, the sensor interprets that measurement as the presence of a vehicle. The received ultrasonic energy is converted into electrical energy that is analyzed by signal processing electronics that is either collocated with the transducer or placed in a roadside controller.

Advantages

Installation of ultrasonic sensors does not require an invasive pavement procedure. Also, some models feature multiple lane operation.

Disadvantages

Temperature change and extreme air turbulence may affect the performance of ultrasonic sensors. Temperature compensation is built into some models. Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.

3
SENSOR DESIGN

3.1 Introduction

In our model we have used fiber optic sensors. Optical fiber, being a physical medium, is subjected to perturbation of one kind or the other at all times. It therefore experiences geometrical and optical changes to a larger or lesser extent depending upon the nature and the magnitude of the perturbation. In communication applications one tries to minimize such effects so that signal transmission and reception is reliable. On the other hand in fiber optic sensing, the response to external influence is deliberately enhanced so that the resulting change in optical radiation can be used as a measure of the external perturbation. In communication, the signal passing through a fiber is already modulated, while in sensing, the fiber acts as a modulator. It also serves as a transducer and converts measurands like temperature, stress, strain, etc. into a corresponding change in the optical radiation. Since light is characterized by amplitude (intensity), phase, frequency and polarization, any one or more of these parameters may undergo a change. The usefulness of the fiber optic sensor therefore depends upon the magnitude of this change and our ability to measure and quantify the same reliably and accurately.

There are a variety of fiber optic sensors. These can be classified as follows.

1. Based on the modulation and demodulation process a sensor can be called as an intensity (amplitude), a phase, a frequency, or a polarization sensor. Since detection of phase or frequency in optics calls for interferometric techniques, the latter are also termed as interferometric sensors.

2. Fiber optic sensors can also be classified on the basis of their application: physical sensors (e.g. measurement of temperature, stress, etc.); chemical sensors (e.g. measurement of pH content, etc.); bio-medical sensors (to measure blood flow, glucose content and so on).

3. Extrinsic or intrinsic sensor is another classification scheme. In the former, sensing takes place in a region outside of the fiber and the fiber essentially serves as a conduit for the to-and-fro transmission of light to the sensing region efficiently and in a desired form. On the other hand, in an intrinsic sensor one or more of the physical properties of the fiber undergo a change as mentioned in 1.

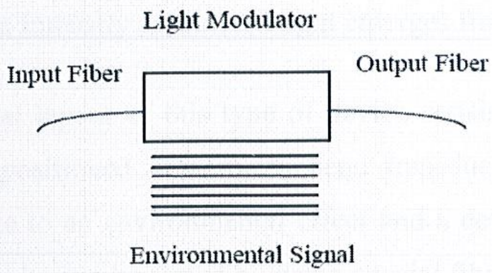


Figure 3.1 Extrinsic fiber optic sensors that modulate the light beam passing through it in response to an environmental effect.

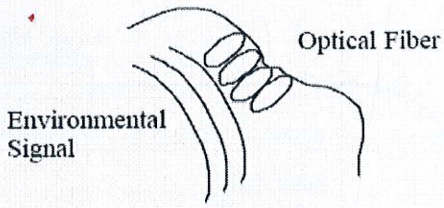


Figure 3.2 Intrinsic fiber optic sensors that modulate the light beam by the environmental effect either directly or through environmentally induced optical path length changes in the fiber itself.

In our model we have employed an intrinsic intensity modulated sensor that is micro bend sensor.

3.2 Micro bend Sensor

The modulation due to a measurand can be brought about in the form of a micro bend loss modulation, moving fiber modulation or an absorbing layer modulation. Micro bend sensor is an intensity modulation sensor. A micro bend sensor is shown in Fig.3.3.

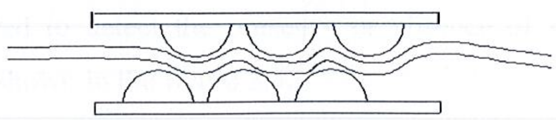


Figure 3.3 Micro bend sensor

It is designed using multimode fiber of a few meters in length which is placed between two rigid plates having an optimum corrugation profile such that the fiber experiences multiple bends. Due to the micro bending induced losses, the lower order guided modes are converted to higher order modes and are eventually lost by radiation into the outer layers resulting in a reduction of the optical intensity coming out of the fiber. A displacement of the plates (due to say, pressure) causes a change in the amplitude of the bends and consequently an intensity modulated light emerges from the fiber core.

Figure 3.4 shows a typical layout of this type of device consisting of a light source, a section of optical fiber positioned in a micro bend transducer designed to intensity modulate light in response to an environmental effect and a detector. In some cases the micro bend transducer can be implemented by using special fiber cabling or optical fiber that is simply optimized to be sensitive to micro bending loss.

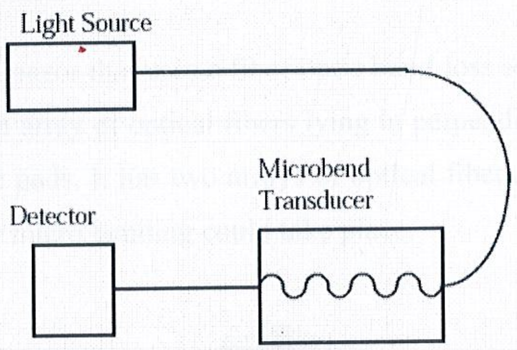


Figure 3.4 Basic setup for micro bend fiber sensors

3.3 Sensing mechanism setup

The above described micro bending loss mechanism can be used to detect the presence or absence of a vehicle. Whenever a vehicle passes over the shocker having an optimum corrugation profile mounted over the fiber optic bed, light beam through the cables undergo micro bending and thus results in the power loss. The input power and the output power can be compared to detect the presence or absence of vehicle. The design of sensing mechanism is shown in the figure 3.5.

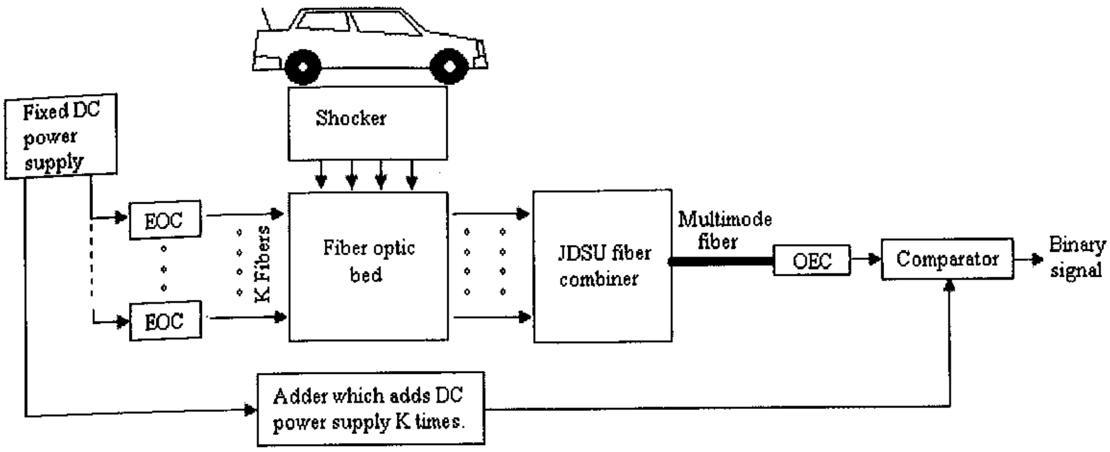


Figure 3.5 Basic setup of sensing mechanism.

3.3.1 Electrical to optical converter

It converts a fixed DC supply to a optical frequency.

3.3.2 Fiber optic bed

A 2 × 2 prototype shear sensor that uses a fiber-optic bend-loss sensor array will be used. The sensor consists of an array of optical fibers lying in perpendicular rows and columns separated by elastomeric pads. It has two arrays of optical fibers placed perpendicular to each other so that proper micro bending could take place.

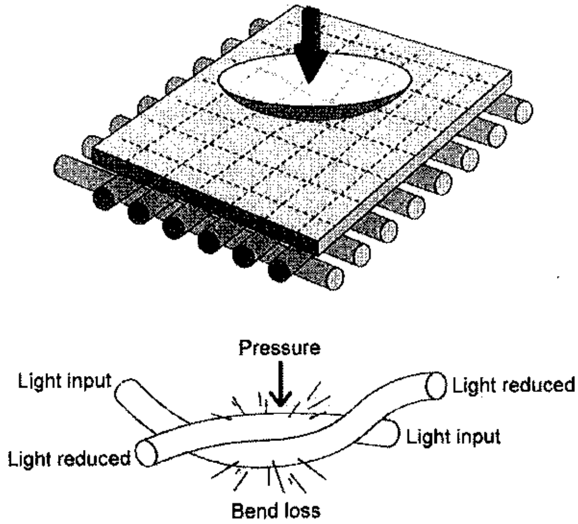


Figure 3.6 Fiber optic bed.

3.3.3 Optical to electrical converter

It converts the variation of optical power into a corresponding varying electric current. For this purpose photo detectors are in existence. Among these are photomultipliers, pyroelectric detectors, semiconductor based photoconductors, phototransistors, and photodiodes.

3.3.4 JDSU fiber combiner

JDSU fiber combiner, can couple 10, 16, or 20 multimode fiber inputs into a single multimode output. This fiber combiner can be a useful component when coupling power from several multimode laser diodes to create a single, high power output source.

3.3.5 Shocker

Shocker is used to reduce the pressure applied by the vehicles. In this way, the fibers are shielded from undue damage.

3.3.6 Working

A fixed DC voltage is fed to each of EOC, due to which a beam of light is launched into each the fiber of the fiber bed. At the other end of the fiber bed the output from each fiber is fed to the JDSU fiber combiner. From the fiber combiner, the resultant power is launched into a single multimode fiber. Now optical power received is fed to detection circuitry. After converting this optical signal back to the electrical signal, comparator is used. Comparator has one input as the electrical signal received and the other one is summation of all the DC voltages fed to the EOC. If the vehicle has/has not passed over the fiber bed then obviously the received DC signal will be less than/equal to the DC signal which was fed to EOC and the output of comparator can be used to detect the presence or absence of vehicle.

Thus by using the above described design we can detect whether the vehicle has crossed the fiber bed or not. One of the disadvantage of fiber optic sensors is the potential for breaking of the fiber in intrinsic sensors due to its delicate structure when a load is applied to it such as from a vehicle crossing over it. So as to overcome this disadvantage, a fiber bed is used instead of a single optical fiber. Even if some of the cables break down, the presence or absence of vehicle can be detected until all cables in the fiber bed break down.

4
SYSTEM DESIGN

In this chapter we are going to discuss our model or setup of intelligent traffic control system. Here we would be discussing the model as well as the algorithm used to control the traffic flow for a 4 - way crossing.

4.1 Overview of design

Each lane of a 4-way crossing is divided into three sub-lanes. This can be done easily by placing two columns of dividers on a lane. These dividers can be placed at a fixed distance before the crossing. The distance will be good enough for the driver to make up his mind about the sub-lane which he wishes to choose. Such dividers are already in place for right sub-lanes in New Delhi. Since there is no control system required for left turning vehicles, signaling is needed only for right going and straight going traffic.

Therefore, except for the left sub-lane, sensors will be put up in the remaining sub-lanes of each of the 4 lanes of the intersection. Thus, there will be 2 sensors for each lane which results in total of 8 sensors for the complete system. Again, these sensors will be placed at the same distance from the intersection from which the dividers appear on the road. The role of these sensors is to count the number of vehicles present in a particular sub-lane. This count is needed by the intelligent traffic control system to identify the busiest lane as well as the busiest sub-lane of that particular lane.

As discussed earlier, we have chosen in-roadway sensor for this purpose. Therefore, the sensors need to be embedded beneath the road. Also, it is a fiber optic based sensor. Using intensity of light as a parameter, pressure applied by the vehicles passing on the road is sensed. There is no need of measuring the amount of pressure applied by the vehicle since we only need to know the number of vehicles passing on a particular sub-lane. This is reasonable because we are only concerned with the accumulation of vehicles vertically and not horizontally. When that sub-lane gets the green signal, both vehicles will cross the intersection simultaneously and hence they can be counted as 1 vehicle only.

As vehicles keep crossing the fiber bed, the sensors keep counting them. All the data is collected and the control box identifies the busiest lane. This is done by summing up the number of vehicles carried by the two sub-lanes of each lane. This lane is given highest priority. The sub-lane carrying more traffic in that lane is also identified. Consider the setup shown in figure 4.1 for a 4-lane crossing.

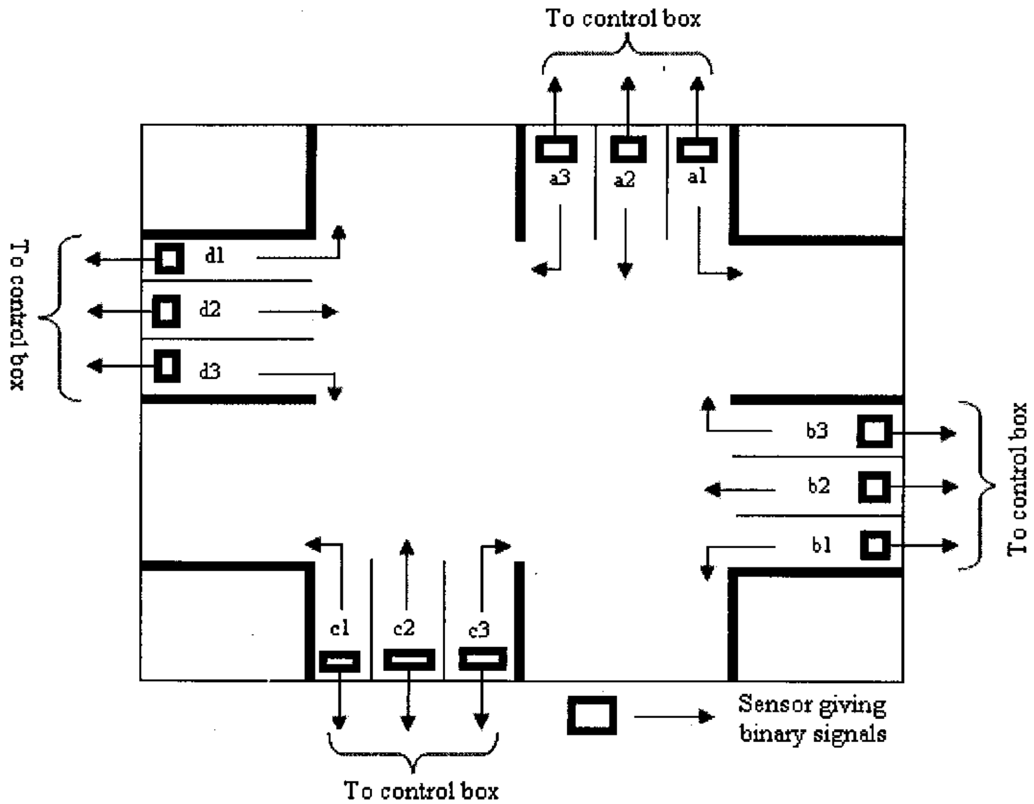


Figure 4.1 Setup for 4 - lane crossing.

4.1.1 Illustration

Assuming that lane A is carrying the heaviest traffic, and between a2 and a3, a2 has more number of vehicles, we can state that lane A should get the maximum priority and a2 must be given green signal immediately. Since a2 carries more traffic, it will be given green signal for more amount of time. Thus, if total time allotted to lane A is T seconds, 2T/3 seconds will be allotted for completing all the processes of a2, remaining T/3 seconds will be dedicated for a3. Consequently, a2 is given the green signal. A few more sub-lanes can also be freed along with a2 in such a way so that traffic is not obstructed. These lanes are a3 and c2. Only one of these two sub-lanes can be given green signal at a particular time. Of these 2 sub-lanes, the sub-lane carrying more traffic is given green signal for a greater duration of time. Again, the allocated duration (T' = 2T/3) is split in 2T'/3 and T'/3. For example, if c2 has more traffic as compared to a3, c2 is given green signal for 4T/9 seconds and a3 is given green signal for 2T/9 seconds. After 2T/3 seconds, a3 is shown green signal. Again, there are 2 sub-lanes which can be freed along with a3. These are a2 and c3. Thus, busier lane is identified among these 2 sub-lanes and again the allocated duration (T" = T/3) is split in 2T"/3 and T"/3. So busier sub lane gets more time to get freed.

This case can be summarized by the following diagram:

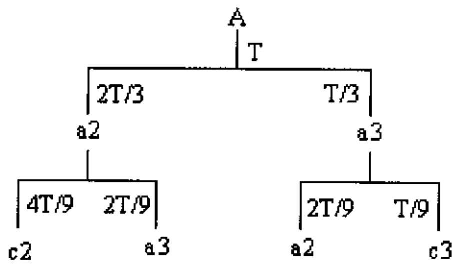


Figure 4.2 Division of time T for an intersection.

In this way, 8 cases can be formulated for lane A alone. If there are 2 lanes carrying the same and maximum amount of traffic, the total allocated time is divided equally among the two lanes and after that time is again divided as explained above for the sub lanes. But if 2 sub lanes carry same amount of traffic then allocated time is again divided equally among the 2 sub lanes.

This was the 1st stage of the 4 stage cycle. The remaining stages will not count traffic present on lane A. Thus, stage 2 involves identification of busiest lane between lanes B,C and D only. Stage 3 involves decision making between 2 lanes only while the last stage is concerned with operation of traffic in the remaining last lane only. The entire cycle is repeated after these 4 stages i.e. all lanes are taken into account while deciding the lane carrying heaviest traffic.

4.1.2 Tie breaker algorithm

If there are 2 lanes carrying the same and maximum amount of traffic, for these situations a tie breaker algorithm is also designed. This algorithm assumes lanes are named and arranged in the clockwise order i.e. A, B, C, D, A, B....so on. The algorithm is given below:

1. If a tie occurs at the starting of a new cycle, then control is always given to one of those tied lanes as per the clockwise order given above.
2. If a tie occurs in between the cycle, then control is given by taking into account the last lane which was given control. Suppose A and C had already been given control and tie occurs between B and D, then if the last lane which was given control was A, then control will be given to B otherwise D will be given control.
3. If a tie occurs between two sub lanes, then control is given to the sub lane corresponding to that lane. For example, if tie occurs between a3 and c2 then control is given to a3 if control was given to lane A during main lane selection.

4.2 Control Box

The block diagram of control box is shown in figure 4.3. The explanation of various modules of control box is given below:

4.2.1 Module 1

As stated before there is sensor employed at each sub lane. The sensor design provides binary signal indicating presence of a vehicle by a high value and absence of a vehicle by low value. This module takes input as binary signals coming from various sub lanes. Whenever signal value goes from a low to a high, count of vehicle for that sub lane is incremented by 1. Accordingly count of vehicles for different sub lanes is written on to the RAM. The four reset signals are used to stop counting as well as resetting the counter of that particular lane. This indicates that control has been given to that lane and its vehicle count is not needed in the future.

4.2.2 Module 2

This module provides the total amount of traffic in a particular lane. Module 1 only gives the count of traffic in a sub lane, but for giving priority, total traffic at each lane is needed. This sum count is also written on to the RAM.

4.2.3 Module 3

This module is one of the main modules of the system. This module selects the order in which lanes should be given control so that they can be freed. While selecting intersection it takes care of the various conditions which were stated before. This module eliminates any tie condition by using the above explained algorithm. The output signal serves as the reset signals for module 1.

4.2.4 Module 4, 5, 6 and 7

These modules provides the various signals to the red, yellow and green (both for going straight and as well as right) lamps of each traffic light employed at each lane. Various signals are generated taking into account the current traffic situation at each sub lane and the corresponding delays.

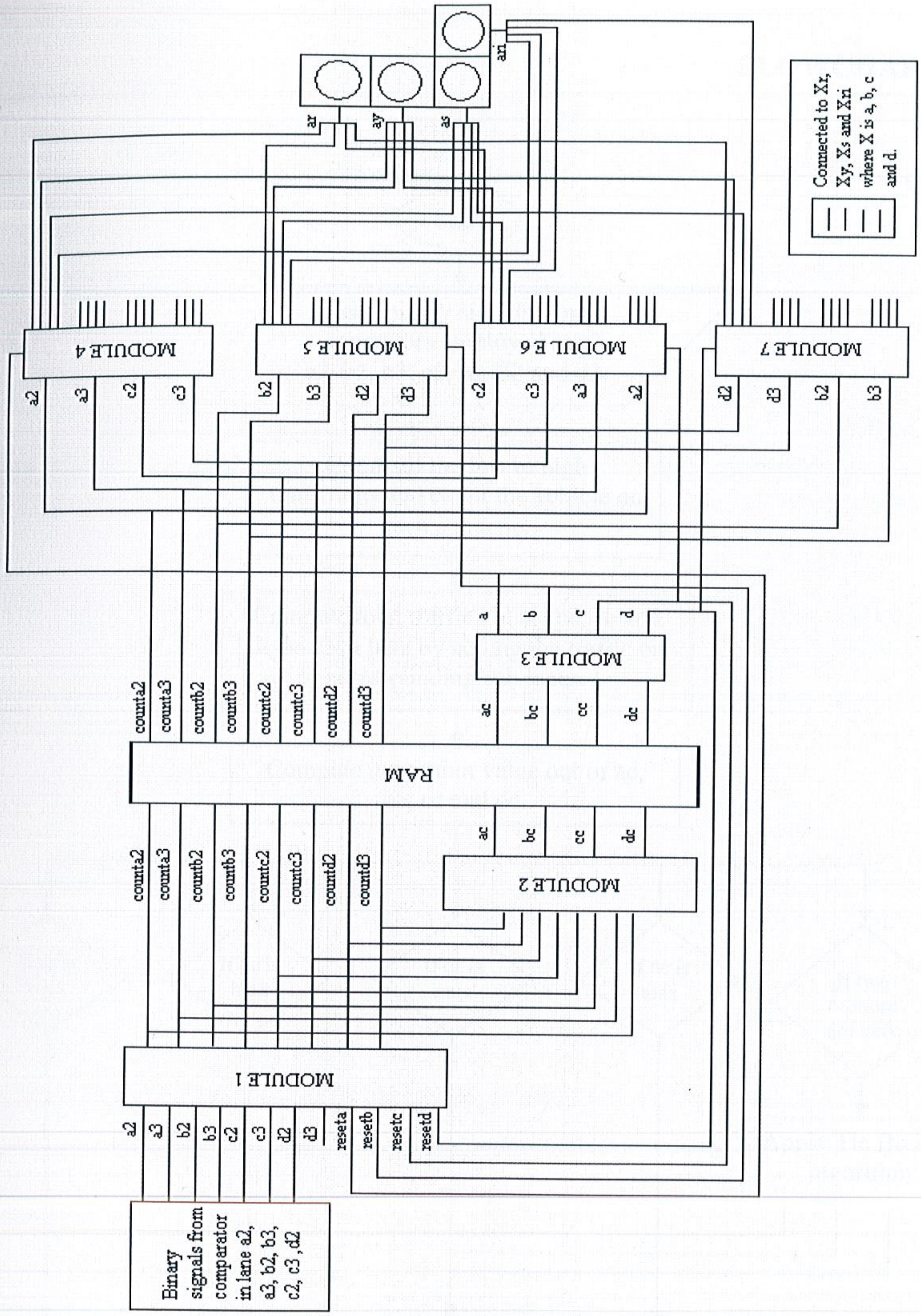
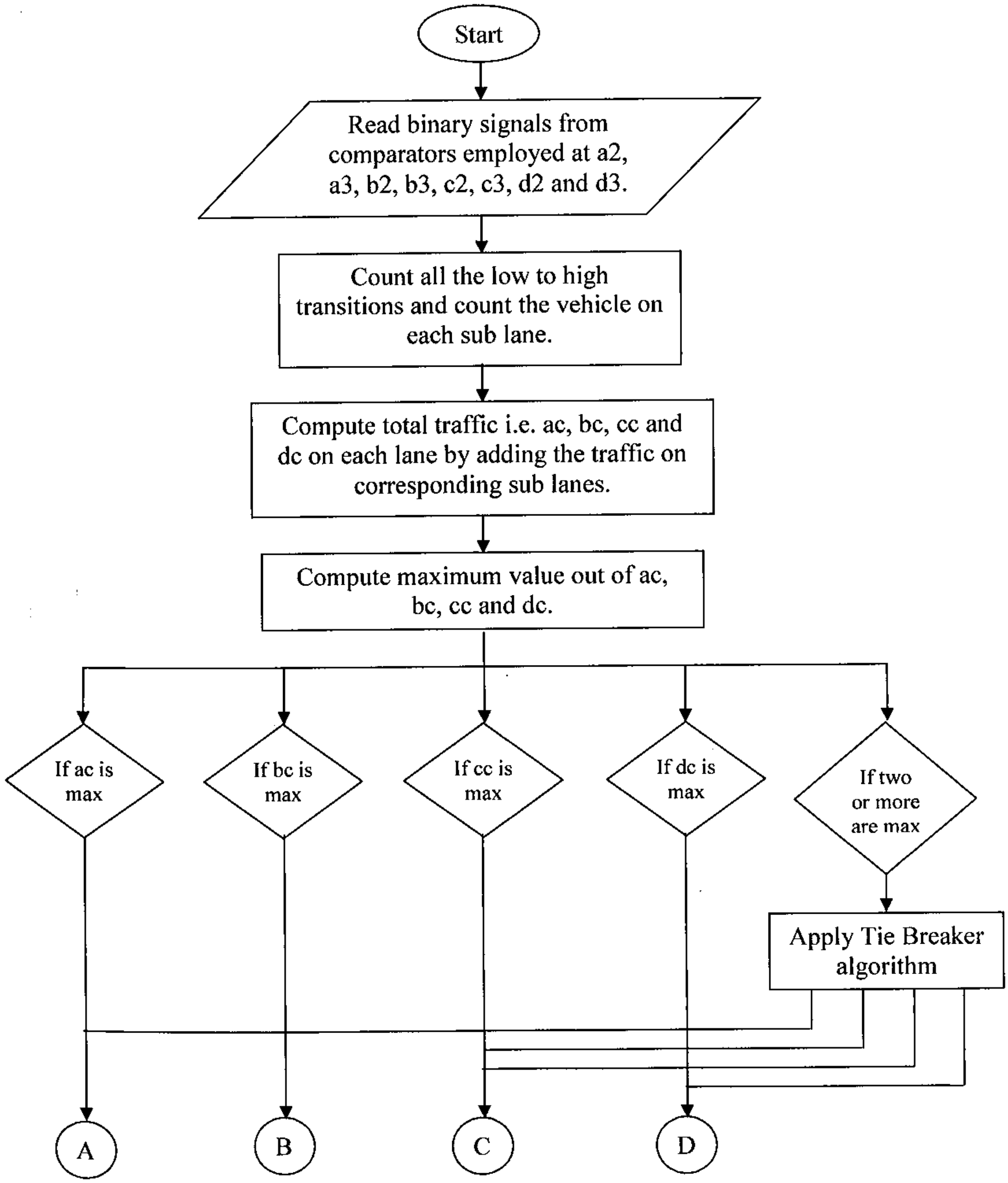
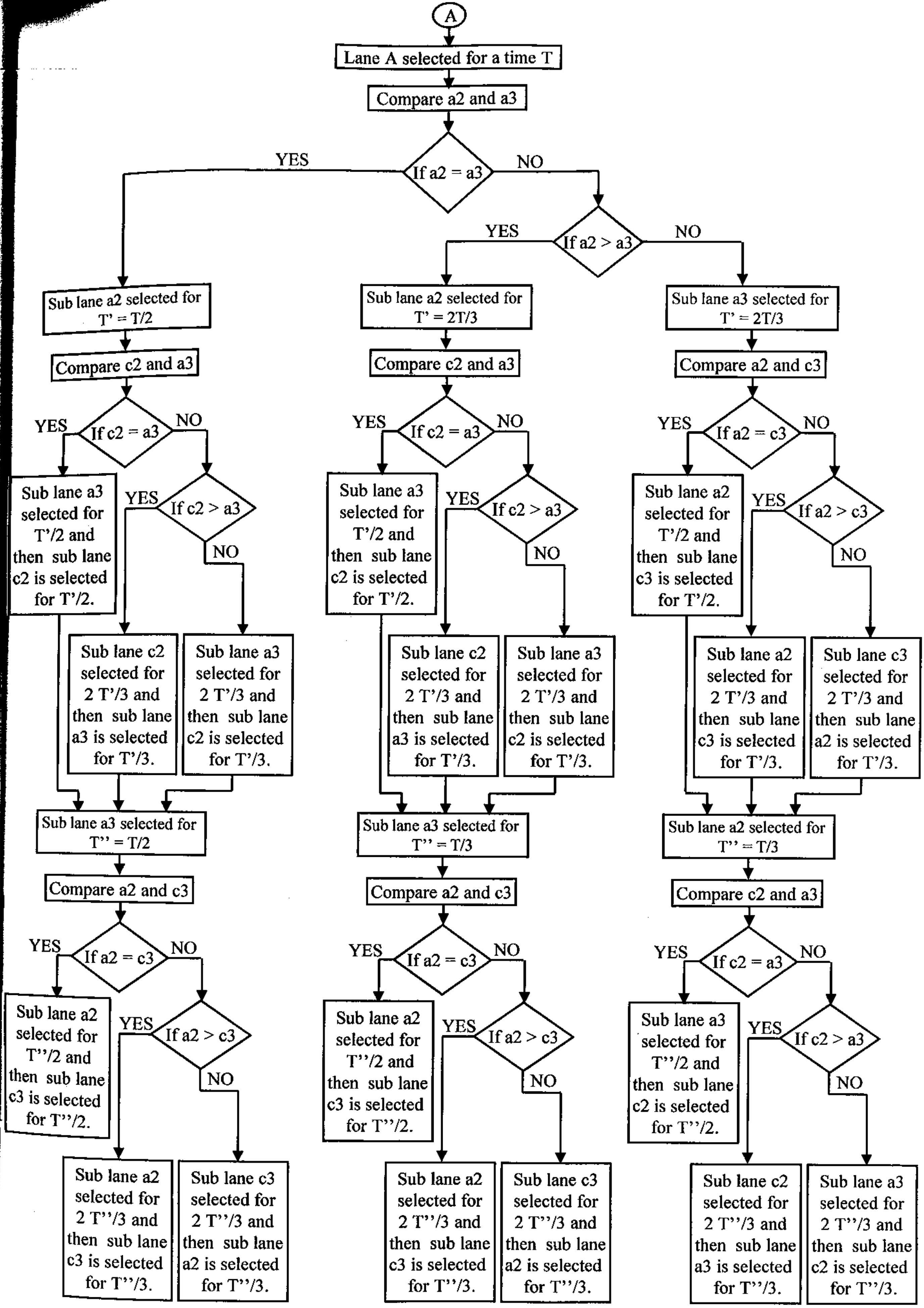


Figure 4.3 Block diagram of control box.

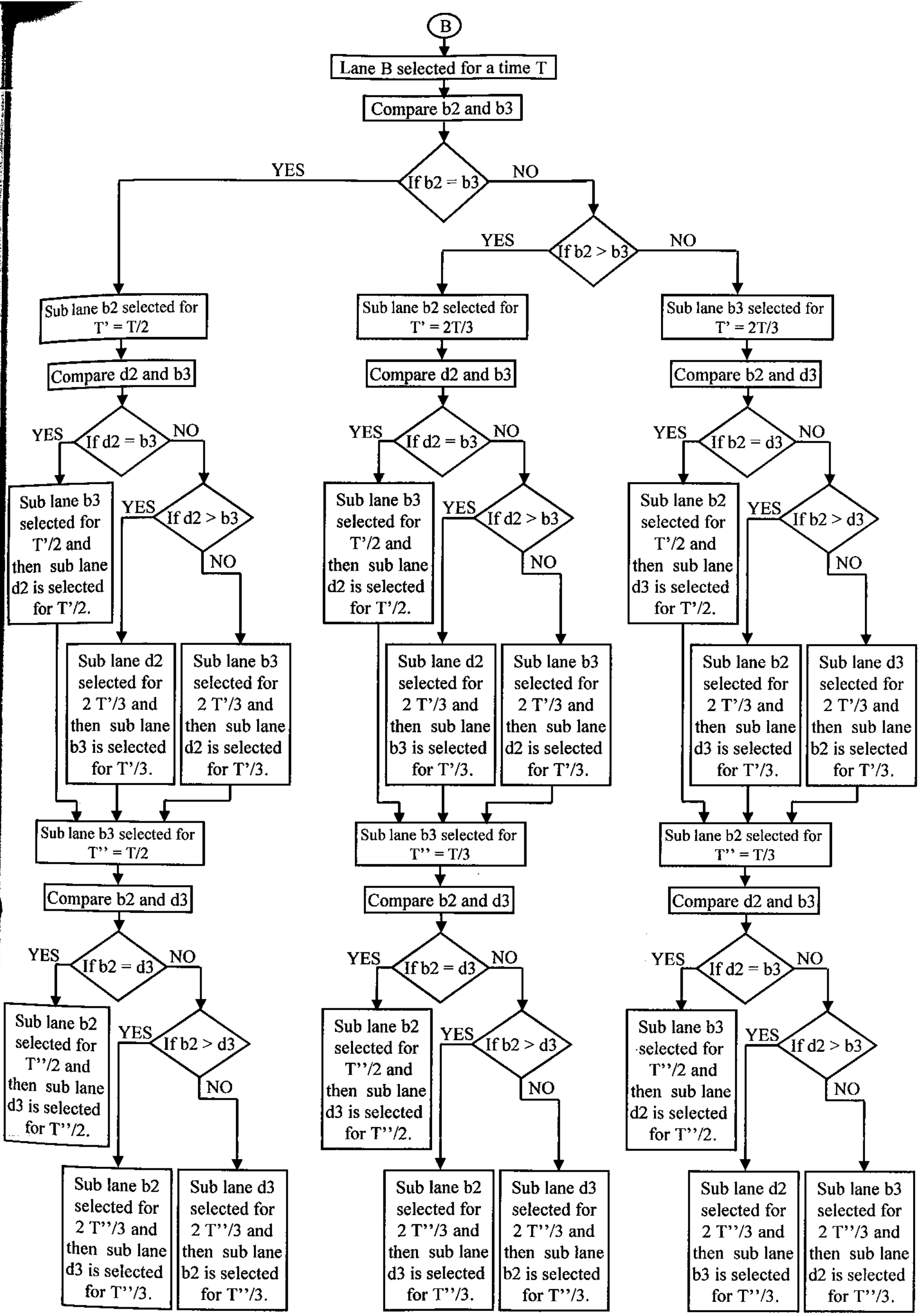
5

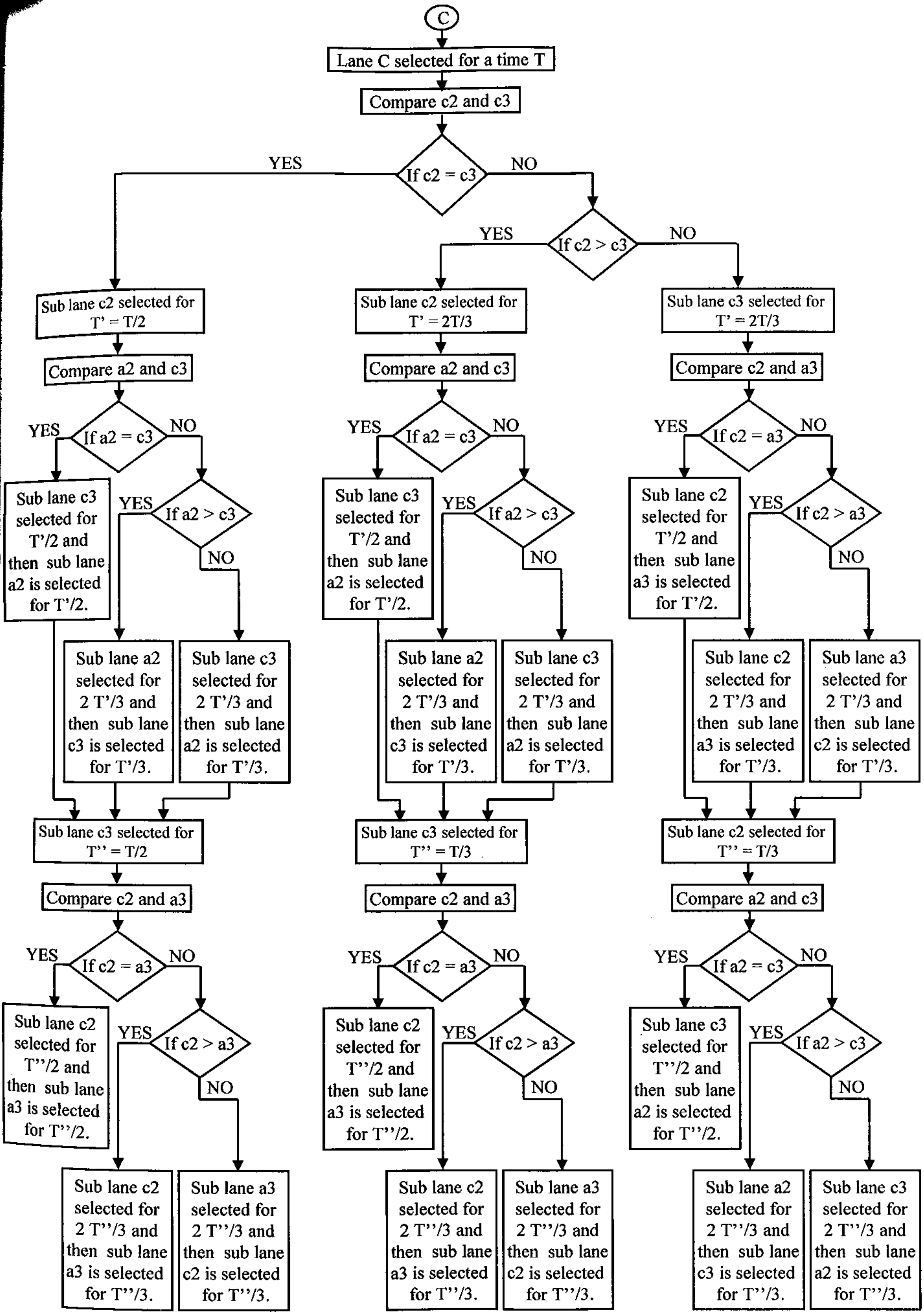
FLOWCHART

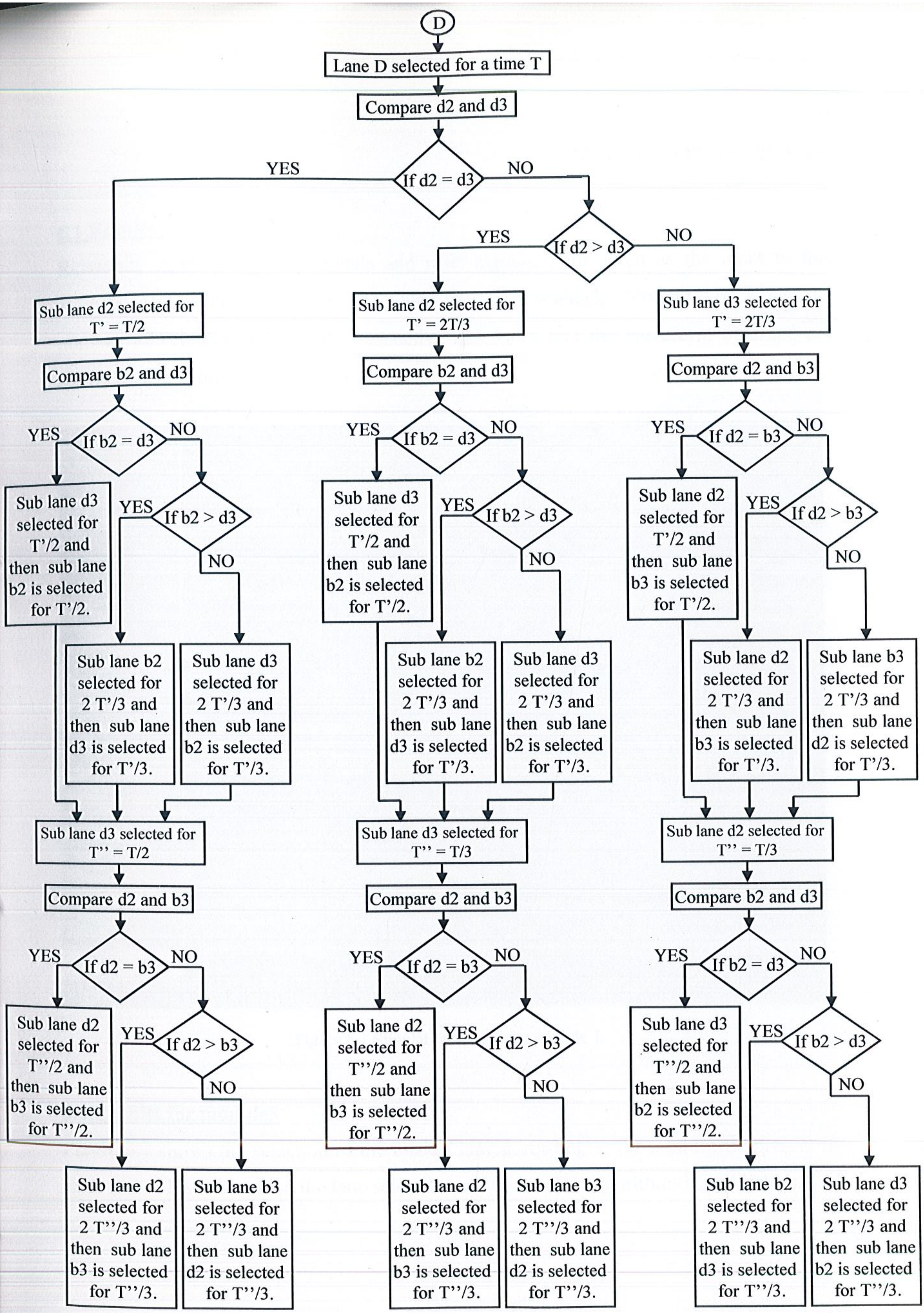

Start
Read binary signals from comparators employed at a2, a3, b2, b3, c2, c3, d2 and d3.
Count all the low to high transitions and count the vehicle on each sub lane.
Compute total traffic i.e. ac, bc, cc and dc on each lane by adding the traffic on corresponding sub lanes.
Compute maximum value out of ac, bc, cc and dc.
If ac is max
If bc is max
If cc is max
If dc is max
If two or more are max
Apply Tie Breaker algorithm
A
B
C
D



A
Lane A selected for a time T
Compare a2 and a3
If a2 = a3
YES
NO
If a2 > a3
YES
NO
Sub lane a2 selected for T' = T/2
Compare c2 and a3
If c2 = a3
YES
NO
Sub lane a3 selected for T'/2 and then sub lane c2 is selected for T'/2.
If c2 > a3
YES
NO
Sub lane c2 selected for 2 T'/3 and then sub lane a3 is selected for T'/3.
Sub lane a3 selected for 2 T'/3 and then sub lane c2 is selected for T'/3.
Sub lane a3 selected for T'' = T/2
Compare a2 and c3
If a2 = c3
YES
NO
Sub lane a2 selected for T''/2 and then sub lane c3 is selected for T''/2.
If a2 > c3
YES
NO
Sub lane a2 selected for 2 T''/3 and then sub lane c3 is selected for T''/3.
Sub lane c3 selected for 2 T''/3 and then sub lane a2 is selected for T''/3.
Sub lane a2 selected for T' = 2T/3
Compare c2 and a3
If c2 = a3
YES
NO
Sub lane a3 selected for T'/2 and then sub lane c2 is selected for T'/2.
If c2 > a3
YES
NO
Sub lane c2 selected for 2 T'/3 and then sub lane a3 is selected for T'/3.
Sub lane a3 selected for 2 T'/3 and then sub lane c2 is selected for T'/3.
Sub lane a3 selected for T'' = T/3
Compare a2 and c3
If a2 = c3
YES
NO
Sub lane a2 selected for T''/2 and then sub lane c3 is selected for T''/2.
If a2 > c3
YES
NO
Sub lane a2 selected for 2 T''/3 and then sub lane c3 is selected for T''/3.
Sub lane c3 selected for 2 T''/3 and then sub lane a2 is selected for T''/3.
Sub lane a3 selected for T' = 2T/3
Compare a2 and c3
If a2 = c3
YES
NO
Sub lane a2 selected for T'/2 and then sub lane c3 is selected for T'/2.
If a2 > c3
YES
NO
Sub lane a2 selected for 2 T'/3 and then sub lane c3 is selected for T'/3.
Sub lane c3 selected for 2 T'/3 and then sub lane a2 is selected for T'/3.
Sub lane a2 selected for T'' = T/3
Compare c2 and a3
If c2 = a3
YES
NO
Sub lane a3 selected for T''/2 and then sub lane c2 is selected for T''/2.
If c2 > a3
YES
NO
Sub lane c2 selected for 2 T''/3 and then sub lane a3 is selected for T''/3.
Sub lane a3 selected for 2 T''/3 and then sub lane c2 is selected for T''/3.


B
Lane B selected for a time T
Compare b2 and b3
If b2 = b3
YES
NO
If b2 > b3
YES
NO
Sub lane b2 selected for T' = T/2
Sub lane b2 selected for T' = 2T/3
Sub lane b3 selected for T' = 2T/3
Compare d2 and b3
Compare d2 and b3
Compare b2 and d3
If d2 = b3
If d2 = b3
If b2 = d3
Sub lane b3 selected for T'/2 and then sub lane d2 is selected for T'/2.
If d2 > b3
Sub lane b3 selected for T'/2 and then sub lane d2 is selected for T'/2.
If d2 > b3
Sub lane b2 selected for T'/2 and then sub lane d3 is selected for T'/2.
If b2 > d3
Sub lane d2 selected for 2 T'/3 and then sub lane b3 is selected for T'/3.
Sub lane b3 selected for 2 T'/3 and then sub lane d2 is selected for T'/3.
Sub lane d2 selected for 2 T'/3 and then sub lane b3 is selected for T'/3.
Sub lane b3 selected for 2 T'/3 and then sub lane d2 is selected for T'/3.
Sub lane b2 selected for 2 T'/3 and then sub lane d3 is selected for T'/3.
Sub lane d3 selected for 2 T'/3 and then sub lane b2 is selected for T'/3.
Sub lane b3 selected for T'' = T/2
Sub lane b3 selected for T'' = T/3
Sub lane b2 selected for T'' = T/3
Compare b2 and d3
Compare b2 and d3
Compare d2 and b3
If b2 = d3
If b2 = d3
If d2 = b3
Sub lane b2 selected for T''/2 and then sub lane d3 is selected for T''/2.
If b2 > d3
Sub lane b2 selected for T''/2 and then sub lane d3 is selected for T''/2.
If b2 > d3
Sub lane b3 selected for T''/2 and then sub lane d2 is selected for T''/2.
If d2 > b3
Sub lane b2 selected for 2 T''/3 and then sub lane d3 is selected for T''/3.
Sub lane d3 selected for 2 T''/3 and then sub lane b2 is selected for T''/3.
Sub lane b2 selected for 2 T''/3 and then sub lane d3 is selected for T''/3.
Sub lane d3 selected for 2 T''/3 and then sub lane b2 is selected for T''/3.
Sub lane d2 selected for 2 T''/3 and then sub lane b3 is selected for T''/3.
Sub lane b3 selected for 2 T''/3 and then sub lane d2 is selected for T''/3.


C
Lane C selected for a time T
Compare c2 and c3
If c2 = c3
YES
NO
If c2 > c3
YES
NO
Sub lane c2 selected for T' = T/2
Sub lane c2 selected for T' = 2T/3
Sub lane c3 selected for T' = 2T/3
Compare a2 and c3
If a2 = c3
YES
NO
Sub lane c3 selected for T'/2 and then sub lane a2 is selected for T'/2.
If a2 > c3
YES
NO
Sub lane a2 selected for 2 T'/3 and then sub lane c3 is selected for T'/3.
Sub lane c3 selected for 2 T'/3 and then sub lane a2 is selected for T'/3.
Compare c2 and a3
If c2 = a3
Sub lane c2 selected for T'/2 and then sub lane a3 is selected for T'/2.
If c2 > a3
Sub lane c2 selected for 2 T'/3 and then sub lane a3 is selected for T'/3.
Sub lane a3 selected for 2 T'/3 and then sub lane c2 is selected for T'/3.
Sub lane c3 selected for T'' = T/2
Sub lane c3 selected for T'' = T/3
Sub lane c2 selected for T'' = T/3
Compare c2 and a3
Compare a2 and c3
Sub lane c2 selected for T''/2 and then sub lane a3 is selected for T''/2.
Sub lane c2 selected for 2 T''/3 and then sub lane a3 is selected for T''/3.
Sub lane a3 selected for 2 T''/3 and then sub lane c2 is selected for T''/3.
Sub lane c3 selected for T''/2 and then sub lane a2 is selected for T''/2.
Sub lane a2 selected for 2 T''/3 and then sub lane c3 is selected for T''/3.
Sub lane c3 selected for 2 T''/3 and then sub lane a2 is selected for T''/3.


D
Lane D selected for a time T
Compare d2 and d3
If d2 = d3
YES
NO
If d2 > d3
YES
NO
Sub lane d2 selected for T' = T/2
Sub lane d2 selected for T' = 2T/3
Sub lane d3 selected for T' = 2T/3
Compare b2 and d3
Compare b2 and d3
Compare d2 and b3
If b2 = d3
If b2 = d3
If d2 = b3
Sub lane d3 selected for T'/2 and then sub lane b2 is selected for T'/2.
If b2 > d3
Sub lane b2 selected for 2 T'/3 and then sub lane d3 is selected for T'/3.
Sub lane d3 selected for 2 T'/3 and then sub lane b2 is selected for T'/3.
Sub lane d3 selected for T'/2 and then sub lane b2 is selected for T'/2.
If b2 > d3
Sub lane b2 selected for 2 T'/3 and then sub lane d3 is selected for T'/3.
Sub lane d3 selected for 2 T'/3 and then sub lane b2 is selected for T'/3.
Sub lane d2 selected for T'/2 and then sub lane b3 is selected for T'/2.
If d2 > b3
Sub lane d2 selected for 2 T'/3 and then sub lane b3 is selected for T'/3.
Sub lane b3 selected for 2 T'/3 and then sub lane d2 is selected for T'/3.
Sub lane d3 selected for T'' = T/2
Sub lane d3 selected for T'' = T/3
Sub lane d2 selected for T'' = T/3
Compare d2 and b3
Compare d2 and b3
Compare b2 and d3
If d2 = b3
If d2 = b3
If b2 = d3
Sub lane d2 selected for T''/2 and then sub lane b3 is selected for T''/2.
If d2 > b3
Sub lane d2 selected for 2 T''/3 and then sub lane b3 is selected for T''/3.
Sub lane b3 selected for 2 T''/3 and then sub lane d2 is selected for T''/3.
Sub lane d2 selected for T''/2 and then sub lane b3 is selected for T''/2.
If d2 > b3
Sub lane d2 selected for 2 T''/3 and then sub lane b3 is selected for T''/3.
Sub lane b3 selected for 2 T''/3 and then sub lane d2 is selected for T''/3.
Sub lane d3 selected for T''/2 and then sub lane b2 is selected for T''/2.
If b2 > d3
Sub lane b2 selected for 2 T''/3 and then sub lane d3 is selected for T''/3.
Sub lane d3 selected for 2 T''/3 and then sub lane b2 is selected for T''/3.

6

SIMULATION RESULTS

6.1 Results for module 1

Randomly generated binary signals and reset signals were given as the input to this module. The values for output variables counta2, counta3,.....countd3 represent the number of vehicles crossing the respective sub lanes and the waveform obtained are shown in figure 6.1.

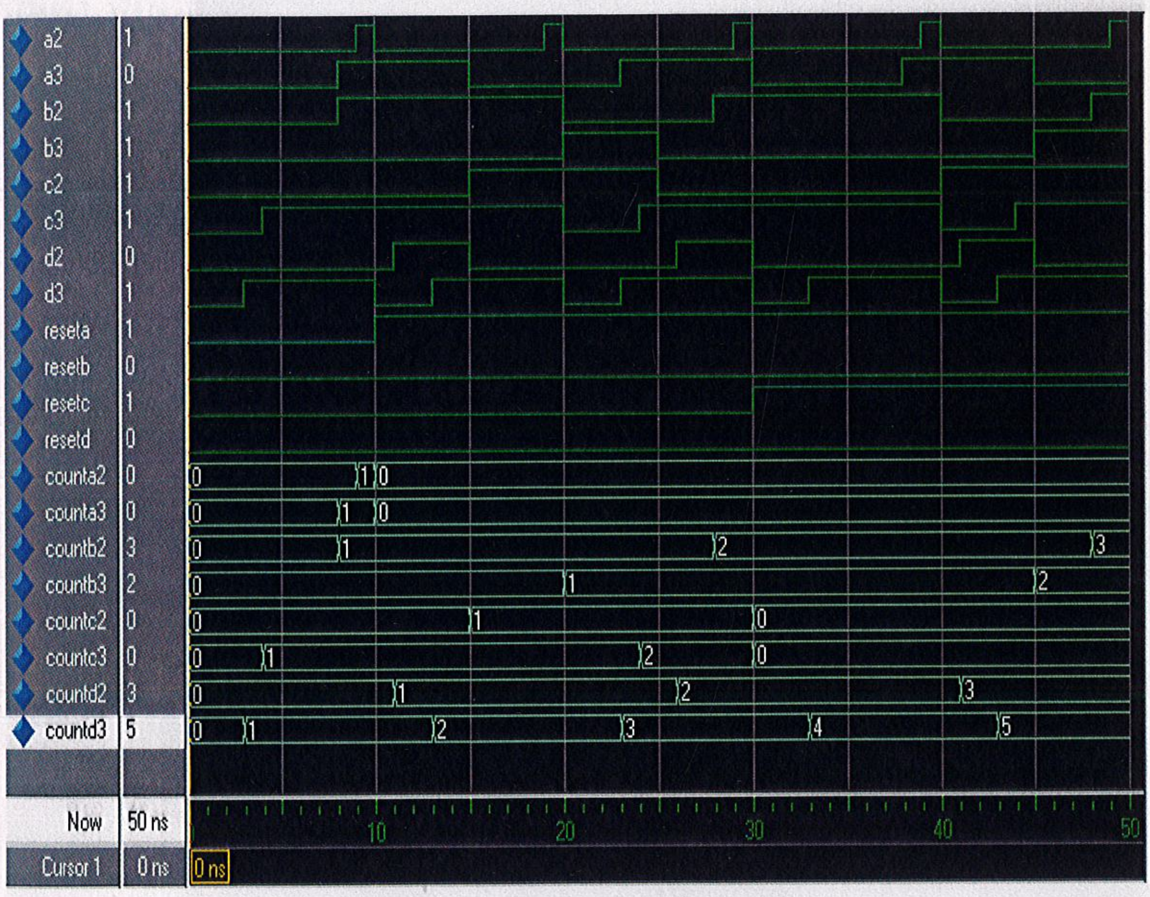


Figure 6.1 Simulation results for module 1.

6.2 Results for module3

Figure 6.2 shows the selection of the busiest lane according to the total traffic present in each lane. This is based on the lane selection and tie breaker algorithms stated before.

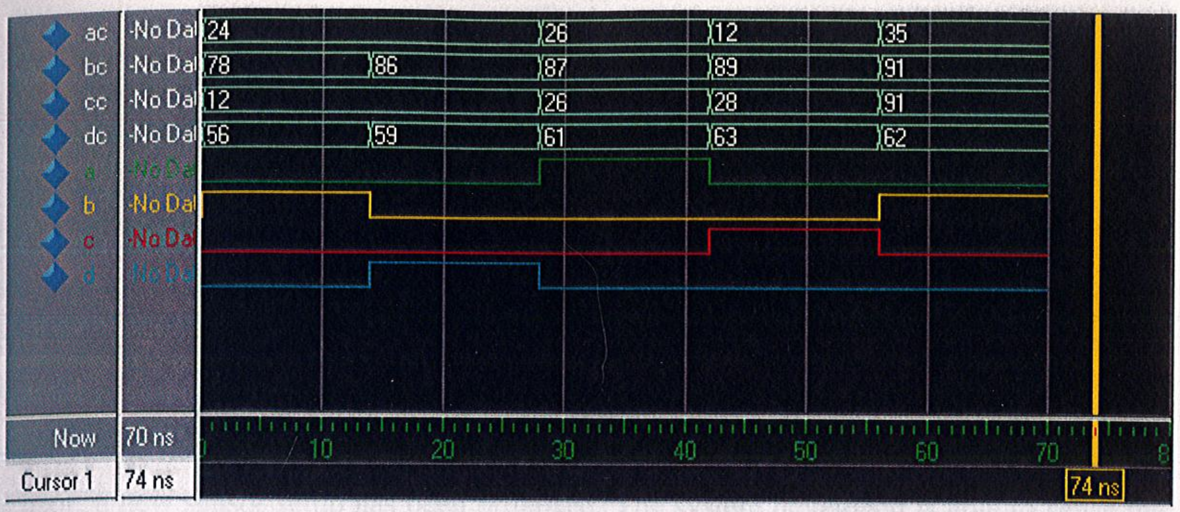


Figure 6.2 Simulation results for module 3.

6.3 Results for module 4

Figure 6.3 shows traffic light simulation for all the four lanes.

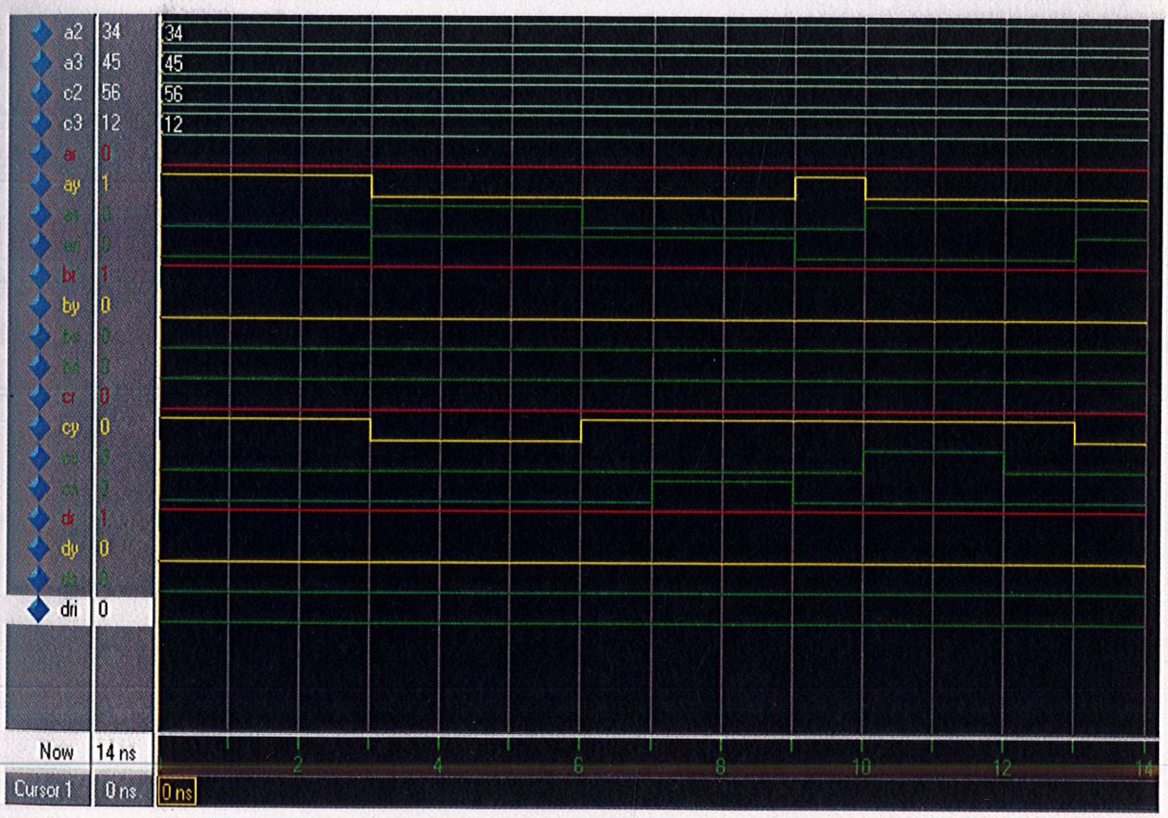


Figure 6.3 Simulation results for module 4.

7
CONCLUSION

In the present work a feasible, affordable, rugged, robust and reliable traffic control system which solves the problem of traffic congestion to an extent has been proposed. Number of vehicles present in a sub lane has been considered as decisive parameter for switching of traffic lights. After comparison among different sensing techniques, fiber optic sensor has been chosen. So as to overcome some of the disadvantages of fiber optic sensor, a new sensor setup has been proposed. The system developed is able to sense the presence or absence of vehicles within certain range by setting the appropriate duration for the traffic signals to react accordingly. To solve the problem of traffic congestion, lane selection and tie breaker algorithms has been designed. The algorithms have been tested with arbitrary test data and have yielded satisfactory results.

Complete simulation of intelligent traffic light system had successfully been designed and developed using ModelSim Se 6.1d. This prototype can be implemented in real life situations. The new timing scheme that was implemented promises an improvement in the current traffic light system. Though there is always a scope of improvement in algorithms, so both the proposed algorithms can be improved to yield much better results. The present work can be extended to be operated by microcontroller. Moreover, the technique can be easily applied on a T-way crossing.

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[7] www.nmsu.edu/~traffic

Pseudo code for the algorithm designed is given below:

5.1 Module 1

```
-- a2, a3, b2, b3, c2, c3, d2 and d3 are the binary signals from comparators employed at
-- sub lanes in each lane. Counta2, counta3, countb2, countb3, countc2, countc3, countd2
-- and countd3 are vehicle count of various lanes. Reseta, resetb, resetc and resetd are the
-- reset signals, when these signal gets high then module make the corresponding count
-- equal to 0 and stop counting for that lane

entity count_vehicle is
input binary signals: a2, a3, b2, b3, c2, c3, d2, d3, reseta, resetb, resetc, resetd;
output signals: counta2,counta3,countb2,countb3,countc2,countc3,countd2,countd3;
end count_vehicle;

architecture count_vehicle of count_vehicle is
begin
process(a2,a3,reseta)
Initialize variables abc1 and abc2 with 0;
begin
if reseta is high then
set both abc1 and abc2 to 0;
end if;
if reseta is low and event has occurred on a2 then
if a2 is high then
increment the value of abc1 by 1;
end if;
end if;
if reseta is low and event has occurred on a3 then
if a3 is high then
increment the value of abc2 by 1;
```

```
end if;
end if;
set value of counta2 and counta3 equal to abc1 and abc2 respectively;
end process;

process(b2,b3,resetb)
Initialize variables abc1 and abc2 with 0;
begin
if resetb is high then
set both abc1 and abc2 to 0;
end if;
if resetb is low and event has occurred on b2 then
if b2 is high then
increment the value of abc1 by 1;
end if;
end if;
if resetb is low and event has occurred on b3 then
if b3 is high then
increment the value of abc2 by 1;
end if;
end if;
set value of countb2 and countb3 equal to abc1 and abc2 respectively;
end process;

process(c2,c3,resetc)
Initialize variables abc1 and abc2 with 0;
begin
if resetc is high then
set both abc1 and abc2 to 0;
end if;
if resetc is low and event has occurred on c2 then
```

```
if c2 is high then
increment the value of abc1 by 1;
end if;
end if;
if resetc is low and event has occurred on c3 then
if c3 is high then
increment the value of abc2 by 1;
end if;
end if;
set value of countc2 and countc3 equal to abc1 and abc2 respectively;
end process;

process(d2,d3,resetd)
Initialize variables abc1 and abc2 with 0;
begin
if resetd is high then
set both abc1 and abc2 to 0;
end if;
if resetd is low and event has occurred on d2 then
if d2 is high then
increment the value of abc1 by 1;
end if;
end if;
if resetd is low and event has occurred on d3 then
if d3 is high then
increment the value of abc2 by 1;
end if;
end if;
set value of countd2 and countd3 equal to abc1 and abc2 respectively;
end process;
end count_vehicle;
```

5.2 Module 2

```
-- a2, a3, b2, b3, c2, c3, d2 and d3 are the binary signals from comparators employed at
-- sub lanes in each lane. ac, bc, cc and dc are the total vehicle count at each lane.

entity vehicle_intersection is
input signals: a2,a3,b2,b3,c2,c3,d2,d3;
output signals: ac,bc,cc,dc;
end vehicle_intersection;

architecture vehicle_intersection of vehicle_intersection is
begin
process (a2,a3,b2,b3,c2,c3,d2,d3)
begin
set ac equal to a2 + a3;
set bc equal to b2 + b3;
set cc equal to c2 + c3;
set dc equal to d2 + d3;
end process;
end vehicle_intersection;
```

5.3 Module 3

```
-- Lane is selected by giving a high signal on either a, b, c or d.
entity select_intersection is
input binary signals: ac,bc,cc,dc;
output signals: a,b,c,d;
end select_intersection;

architecture select_intersection of select_intersection is
begin
process
```

```
initialize variable ports and last to "0000" (bit_vector);
Declare a constant max_delay with some initial value;
begin
case ports is
when "0000"|"1111" =>
if ports equal to "1111" then
set ports and last to "0000";
set a,b,c,d to 0;
end if;
if (ac>bc, cc, dc) OR (ac = bc = cc = dc) OR (ac>cc, dc AND ac=bc)
OR (ac>bc, dc AND ac=cc) OR (ac>cc, bc AND ac=dc) then
set a to 1 and ports(1) to 1;
wait for max_delay;
end if;
if  (bc > ac, cc, dc) OR (bc>ac, dc AND cc=bc) OR (bc>cc, ac AND dc = bc)   then
set b to 1 and ports(2) to 1;
wait for max_delay;
end if;
if (cc > bc, ac, dc) OR (cc > ac, bc and cc = dc) then
set c to 1 and ports(3) to 1;
wait for max_delay;
end if;
if dc is greater then bc, ac cc then
set d to 1 and ports(4) to 1;
wait for max_delay;
end if;

when "1000" =>
if  (bc > cc, dc) OR (bc = cc  = dc) OR (bc>dc AND bc = cc) OR (bc>cc AND bc = dc)
then
set b to 1, a to 0, ports(2) to 1 and last to 0100;
```

wait for max_delay;
end if;

if (cc > bc, dc) OR (cc>bc AND dc = cc) then
set c to 1, a to 0, ports(3) to 1 and last to 0010;
wait for max_delay;
end if;
if dc > bc, cc then
set d to 1, a to 0, ports(4) to 1 and last to 0001;
wait for max_delay;
end if;

when "0100" =>
if ac > cc AND ac > dc then
set a to 1, b to 0, ports(1) to 1 and last to 1000;
wait for max_delay;
end if;
if (cc > ac AND cc > dc) OR (ac = cc AND cc = dc) OR (ac > dc AND ac = cc) OR (cc > ac and dc = cc) then
set c to 1, b to 0, ports(3) to 1 and last to 0010;
wait for max_delay;
end if;
if (dc > ac AND dc > cc) OR (ac>cc AND ac = dc) OR then
set d to 1, b to 0, ports(4) to 1 and last to 0001;
wait for max_delay;
end if;

when "0010" =>
if (ac > bc AND ac > dc) OR (ac > dc AND bc = ac) then
set a to 1, c to 0, ports(1) to 1 and last to 1000;
wait for max_delay;

```
end if;
if (bc > ac AND bc > dc) then
set b to 1, c to 0, ports(2) to 1 and last to 0100;
wait for max_delay;
end if;
if (dc > bc AND dc > ac) OR (ac = bc AND bc = dc ) OR (ac > bc AND ac = dc ) OR
(bc > ac AND dc = bc ) then
set d to 1, c to 0, ports(4) to 1 and last to 0001;
wait for max_delay;
end if;

when "0001" =>
if (ac > cc AND ac > bc) OR (ac = bc AND bc = cc) OR (ac > cc AND bc = ac)
OR (ac > bc AND ac = cc) then
set a to 1, d to 0, ports(1) to 1 and last to 1000;
wait for max_delay;
end if;
if (bc > ac AND bc > cc) OR (bc > ac and bc =  cc) then
set b to 1, d to 0, ports(2) to 1 and last to 0100;
wait for max_delay;
end if;
if (cc > bc AND cc > ac) then
set c to 1, d to 0, ports(3) to 1 and last to 0010;
wait for max_delay;
end if;

when "1100" =>
if (cc>dc) OR (cc = dc) then
set c to 1, a to 0, b to 0 and ports(3) to1;
wait for max_delay;
end if;
```

```
if dc>cc then
set d to 1, a to 0, b to 0 and ports(4) to1;
wait for max_delay;
end if;

when "1010" =>
if  (bc > dc) OR (bc = dc AND last = "1000")  then
set b to 1, a to 0, c to 0 and ports(2) to1;
wait for max_delay;
end if;
if  (dc > bc) OR (bc = dc AND last = "0010") then
set d to 1, a to 0, c to 0 and ports(4) to1;
wait for max_delay;
end if;

when "1001" =>
if cc>bc then
set c to 1, a to 0, d to 0 and ports(3) to1;
wait for max_delay;
end if;
if  (bc > cc) OR (bc = cc) then
set b to 1, a to 0, d to 0 and ports(2) to1;
wait for max_delay;
end if;

when "0110" =>
if ac>dc then
set a to 1, b to 0, c to 0 and ports(1) to1;
wait for max_delay;
end if;
if  (dc > ac) OR (ac = dc) then
```

```
set d to 1, b to 0, c to 0 and ports(4) to1;
wait for max_delay;
end if;

when "0101" =>
if (ac > cc) OR (ac = cc ANDlast = "0001")  then
set a to 1, b to 0, d to 0 and ports(1) to1;
wait for max_delay;
end if;
if (cc > ac) OR (ac = cc AND last = "0100") then
set c to 1, b to 0, d to 0 and ports(3) to1;
wait for max_delay;
end if;

when "0011" =>
if  (ac > bc) OR (ac = bc) then
set a to 1, c to 0, d to 0 and ports(1) to1;
wait for max_delay;
end if;
if bc>ac then
set b to 1, c to 0, d to 0 and ports(2) to1;
wait for max_delay;
end if;

when "1110" =>
set d to 1, a to 0, b to 0, c to 0 and ports(2) to1;
wait for max_delay;

when "1101" =>
set c to 1, a to 0, b to 0, d to 0 and ports(3) to1;
wait for max_delay;
```

when "1011" =>

set b to 1, a to 0, c to 0, d to 0 and ports(2) to1;

wait for max_delay;

when "0111" =>

set a to 1, b to 0, c to 0, d to 0 and ports(1) to1;

wait for max_delay;

end case;

end process;

end select_intersection;

5.4 Module 4

-- This is control box for lane A.

entity a_intersection is

input signals: a2,a3,c2,c3;

output binary signals: ar,ay,as,ari,br,by,bs,bri,cr,cy,cs,cri,dr,dy,ds,dri;

end a_intersection;

architecture a_intersection of a_intersection is

begin

process

begin

set signals ar, by, bs, bri, cr, dy, dri, to 0;

set signals br and dr to 1;

wait for total_time;

end process;

process

begin

set signal ay to 1 and introduce appropriate delay;

compare a2 and a3 then

set signal ay to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set signal as to 0 and introduce appropriate delay;
compare a2 and a3 then
compare a2 and c3 then
set signal as to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal ari to 0 and introduce appropriate delay;
compare a2 and a3 then
compare a3 and c2 then
set signal ari to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal cs to 0 and introduce appropriate delay;
comapre a2 and a3 then
compare a3 and c2 then
set signal cs to 0 or 1and introduce appropriate delay;
end process;

process
begin
set signal cri to 0 and introduce appropriate delay;
compare a2 and a3 then

set signal cri to 0 and introduce appropriate delay;
compare a2 and c3 then
set signal cri to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set cy to 1 and introduce appropriate delay;
compare a2 and a3 then
compare a3 and c2 then
set cy to 1 or 0 and introduce appropriate delay;
compare a2 and c3 then
set cy to 1or 0 and introduce appropriate delay
end process;
end a_intersection;

5.5 Module 5

-- This is control box for lane B.
entity b_intersection is
input signals: b2,b3,d2,d3;
output binary signals: ar,ay,as,ari,br,by,bs,bri,cr,cy,cs,cri,dr,dy,ds,dri;
end b_intersection;

architecture b_intersection of b_intersection is
begin
process
begin
set signals br, cy, cs, cri, dr, ay, ari to 0;
set signals cr and ar to 1;
wait for total_time;
end process;

process
begin
set signal by to 1 and introduce appropriate delay;
compare b2 and b3 then
set signal ay to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set signal bs to 0 and introduce appropriate delay;
compare b2 and b3 then
compare b2 and d3 then
set signal as to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal bri to 0 and introduce appropriate delay;
compare b2 and b3 then
compare b3 and d2 then
set signal bri to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal ds to 0 and introduce appropriate delay;
comapre b2 and b3 then
compare b3 and d2 then
set signal ds to 0 or 1and introduce appropriate delay;
end process;

```
process
begin
set signal  dri to 0 and introduce appropriate delay;
compare b2 and b3 then
set signal  dri to 0 and introduce appropriate delay;
compare b2 and d3 then
set signal dri to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set dy to 1 and introduce appropriate delay;
compare b2 and b3 then
compare b3 and d2 then
set dy to 1 or 0 and introduce appropriate delay;
compare  b2 and d3 then
set dy to 1or 0 and introduce appropriate delay
end process;
end b_intersection
```

5.6 Module 6

```
-- This is control box for lane C.
entity c_intersection is
input signals: c2,c3,a2,a3;
output binary signals: ar,ay,as,ari,br,by,bs,bri,cr,cy,cs,cri,dr,dy,ds,dri;
end c_intersection;

architecture c_intersection of c_intersection is
begin
process
```

```
begin
set signals cr, dy, ds, dri, ar, by, bri, to 0;
set signals dr and br to 1;
wait for total_time;
end process;

process
begin
set signal cy to 1 and introduce appropriate delay;
compare c2 and c3 then
set signal  cy to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set signal  cs to 0 and introduce appropriate delay;
compare c2 and c3 then
compare c2 and a3 then
set signal cs to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal  cri to 0 and introduce appropriate delay;
compare c2 and c3 then
compare c3 and a2 then
set signal  cri to 1 or 0 and introduce appropriate delay;
end process;

process
begin
```

set signal as to 0 and introduce appropriate delay;
comapre c2 and c3 then
compare c3 and a2 then
set signal as to 0 or 1and introduce appropriate delay;
end process;

process
begin
set signal ari to 0 and introduce appropriate delay;
compare c2 and c3 then
set signal ari to 0 and introduce appropriate delay;
compare c2 and a3 then
set signal ari to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set ay to 1 and introduce appropriate delay;
compare c2 and c3 then
compare c3 and a2 then
set ay to 1 or 0 and introduce appropriate delay;
compare c2 and a3 then
set ay to 1or 0 and introduce appropriate delay
end process;
end c_intersection

5.7 Module 7

-- This is control box for lane D.
entity d_intersection is
input signals: d2,d3,b2,b3;
output binary signals: ar,ay,as,ari,br,by,bs,bri,cr,cy,cs,cri,dr,dy,ds,dri;

```
end d_intersection;

architecture d_intersection of d_intersection is
begin
process
begin
set signals dr, ay, as, ari, br, cy, cri, to 0;
set signals ar and cr to 1;
wait for total_time;
end process;

process
begin
set signal dy to 1 and introduce appropriate delay;
compare d2 and d3 then
set signal dy to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set signal  ds to 0 and introduce appropriate delay;
compare d2 and d3 then
compare d2 and b3 then
set signal ds to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal  dri to 0 and introduce appropriate delay;
compare d2 and d3 then
compare d3 and b2 then
```

```
set signal  dri to 1 or 0 and introduce appropriate delay;
end process;

process
begin
set signal  bs to 0 and introduce appropriate delay;
comapre  d2 and d3 then
compare d3 and b2 then
set signal bs to 0 or 1and introduce appropriate delay;
end process;

process
begin
set signal  bri to 0 and introduce appropriate delay;
compare d2 and d3 then
set signal  bri to 0 and introduce appropriate delay;
compare d2 and b3 then
set signal  bri to 0 or 1 and introduce appropriate delay;
end process;

process
begin
set by to 1 and introduce appropriate delay;
compare d2 and d3 then
compare d3 and b2 then
set by to 1 or 0 and introduce appropriate delay;
compare  d2 and b3 then
set by to 1or 0 and introduce appropriate delay
end process;
end d_intersection
```