April 21, 1970 J. L. BARKER ET AL 3,508,191

EXPRESSWAY RAMP TRAFFIC CONTROL SYSTEM

Filed Feb. 21, 1967 5 Sheets-Sheet 1

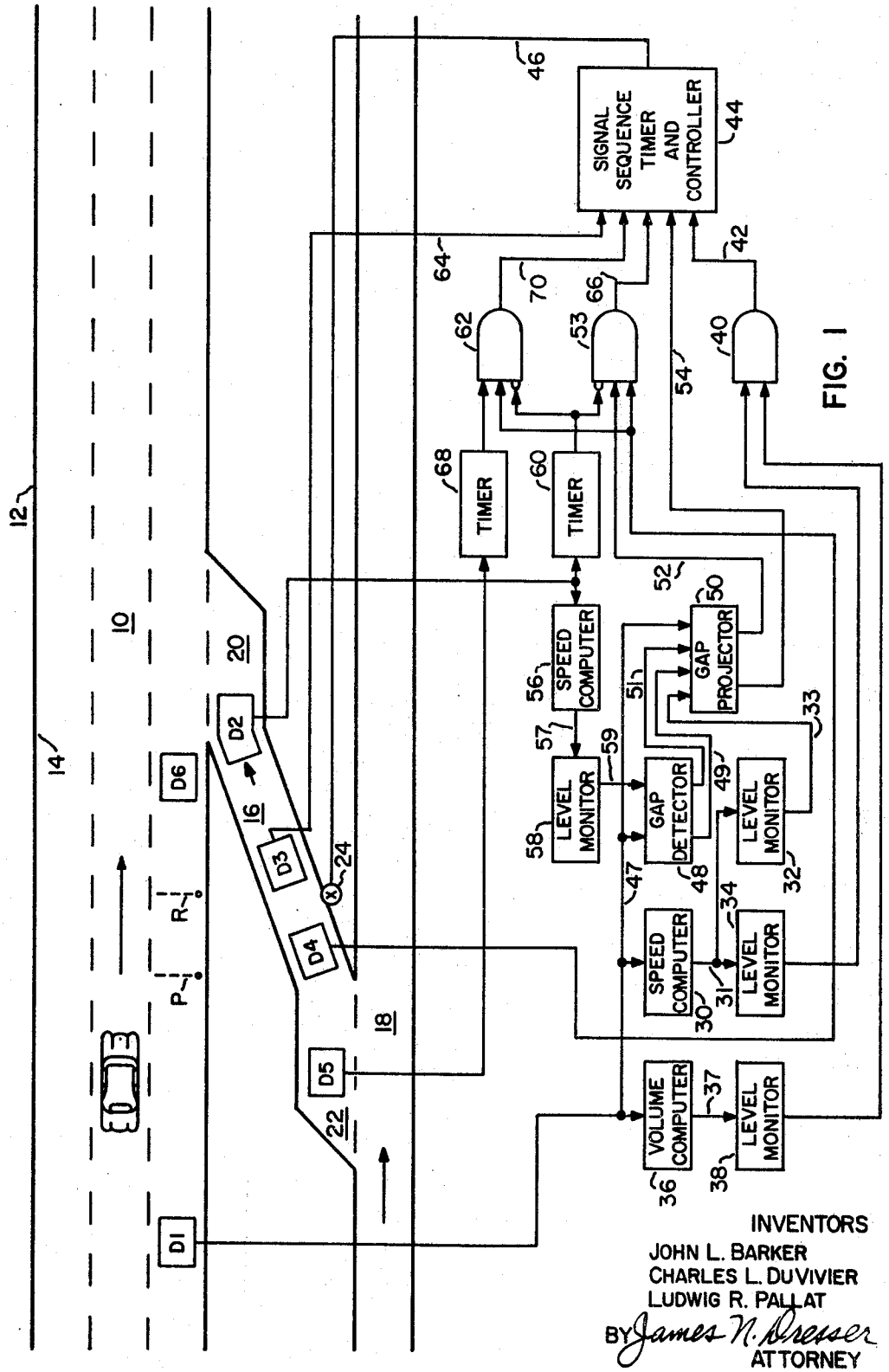


FIG. 1

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EXPRESSWAY RAMP TRAFFIC CONTROL SYSTEM

Filed Feb. 21, 1967 5 Sheets-Sheet 2

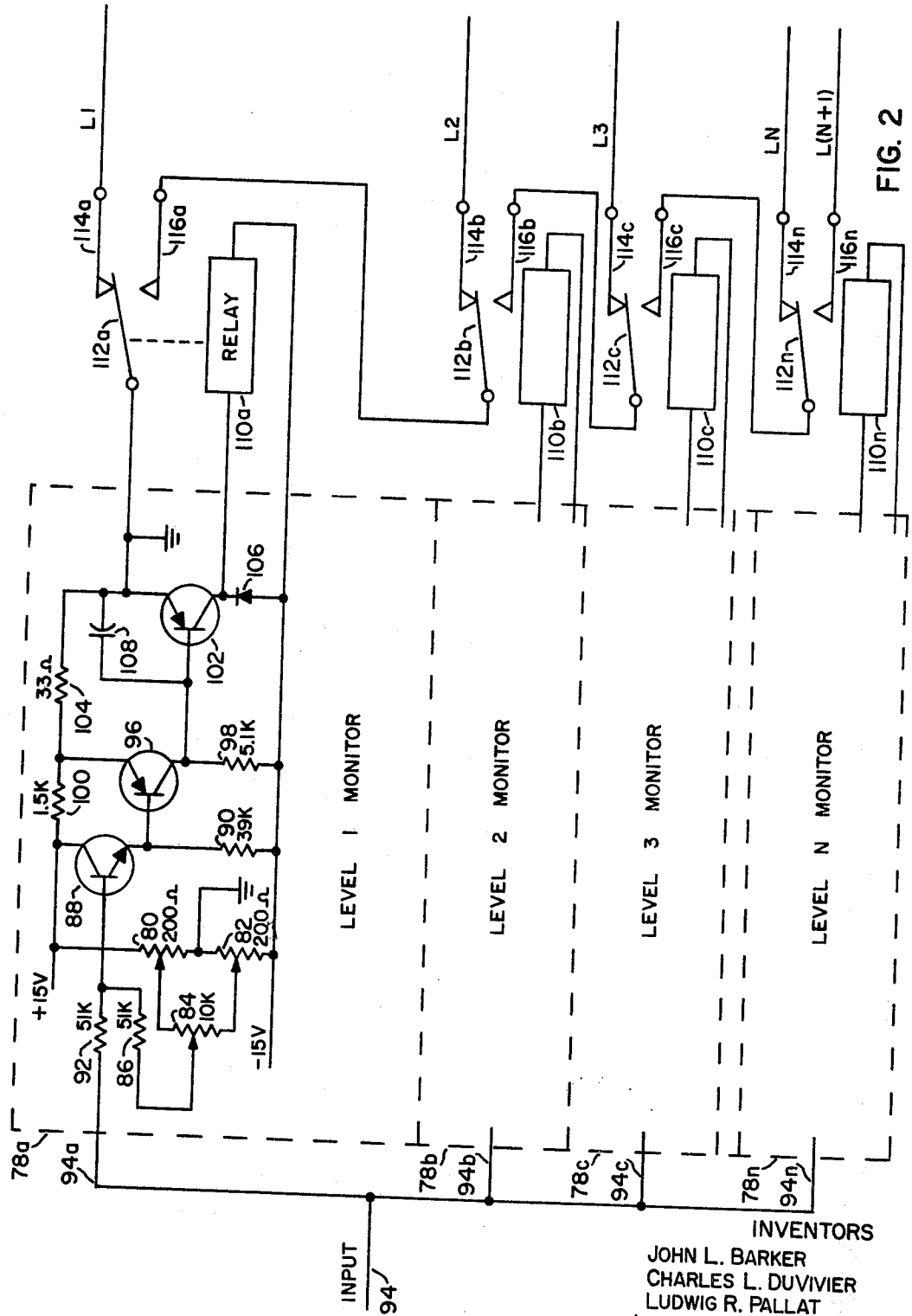


FIG. 2

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EXPRESSWAY RAMP TRAFFIC CONTROL SYSTEM

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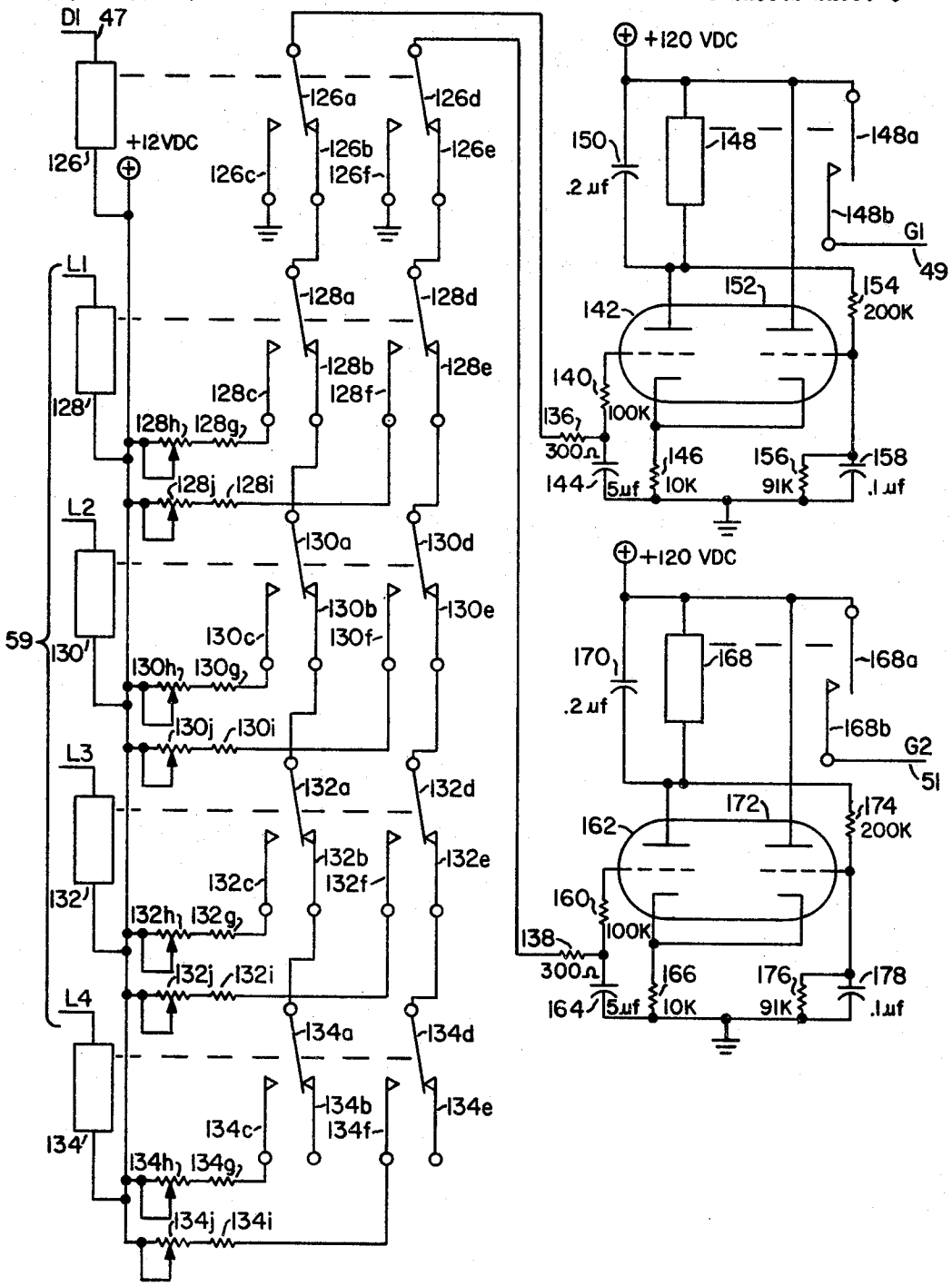


FIG. 3

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EXPRESSWAY RAMP TRAFFIC CONTROL SYSTEM

Filed Feb. 21, 1967 5 Sheets-Sheet 4

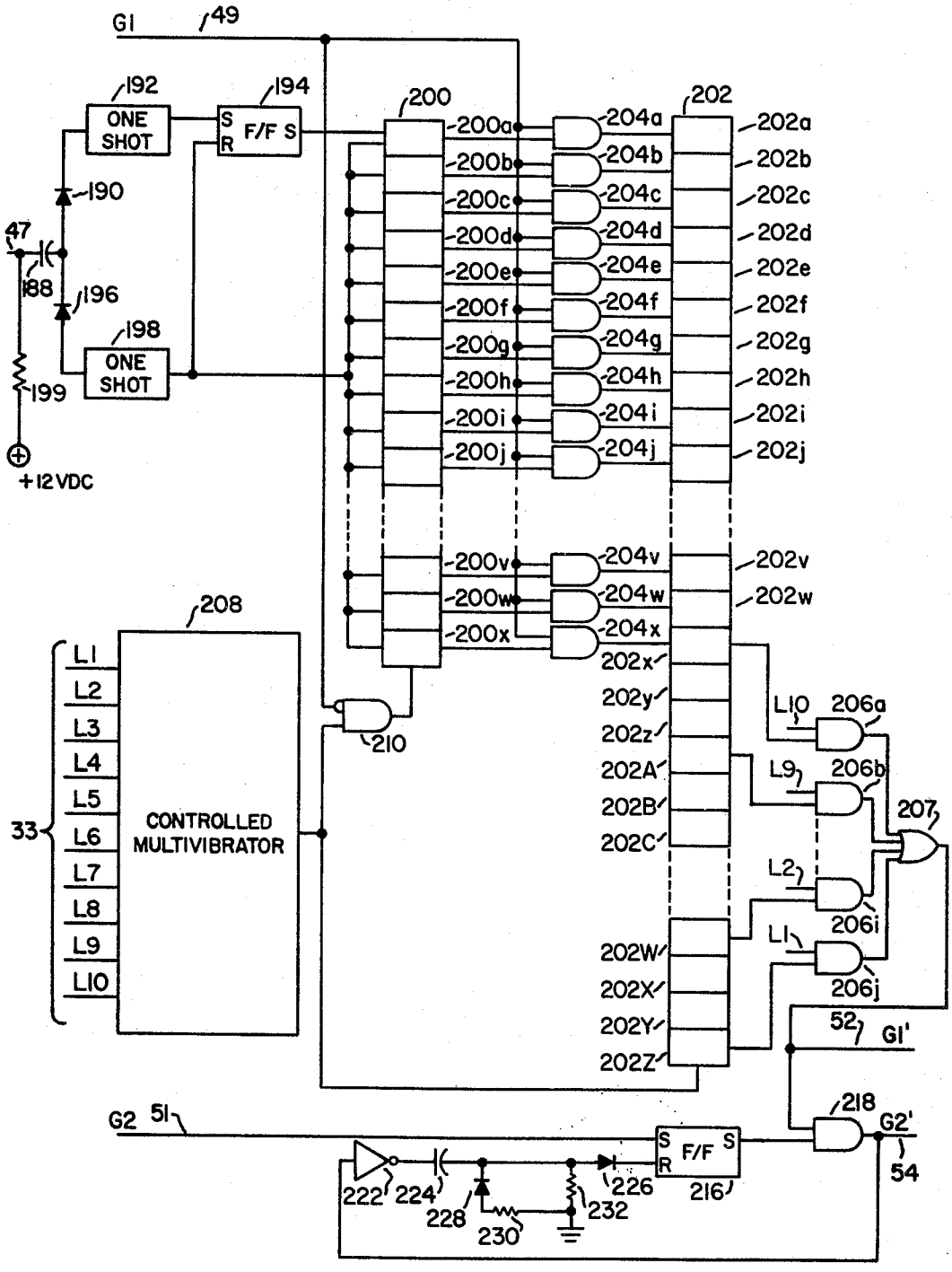


FIG. 4

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EXPRESSWAY RAMP TRAFFIC CONTROL SYSTEM

Filed Feb. 21, 1967 5 Sheets-Sheet 5

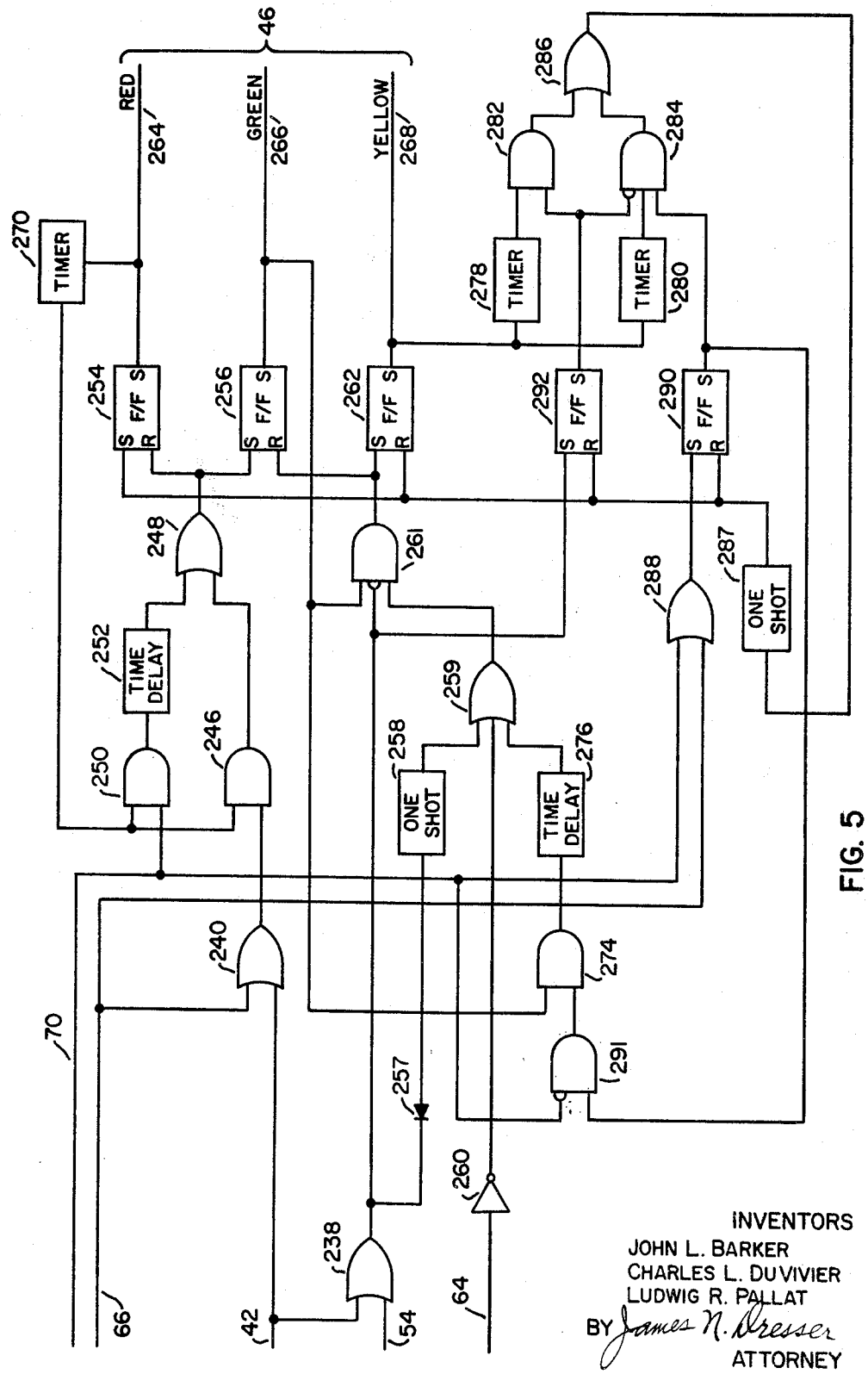


FIG. 5

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United States Patent Office 3,508,191
Patented Apr. 21, 1970

3,508,191

EXPRESSWAY RAMP TRAFFIC CONTROL SYSTEM

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Filed Feb. 21, 1967, Ser. No. 617,567
Int. Cl. G08g 1/08, 1/095
U.S. Cl. 340—36 12 Claims

ABSTRACT OF THE DISCLOSURE

A system for controlling entrance of vehicles onto a limited-access roadway from an entrance ramp. Gaps between vehicles on the roadway are detected upstream of the ramp by means of vehicle detection pulses. Movement of each gap toward the ramp is matched by movement of a gap-indicating signal through a shift register. If a gap is long enough to permit a vehicle to merge into it, the gap-indicating signal is transferred to a second shift register which provides the required delay before operating a traffic control signal adjacent the ramp to release a vehicle, enabling it to reach the merging area when the gap is there.

BACKGROUND OF THE INVENTION

This invention pertains to a highway traffic control system. More particularly this invention pertains to a system for controlling the release of vehicles onto a limited-access roadway from an entrance ramp leading to the limited-access roadway from an adjacent local street or frontage road.

Heavy traffic demands are placed upon the street systems of large metropolitan areas during the periods in the morning and afternoon when large numbers of commuters are traveling to and from work and during other special occasions. This traffic frequently travels substantial distances from the out-skirts of a large city to the downtown central business district, and, to enable it to travel more rapidly, numerous cities have developed systems of limited-access roadways, frequently referred to as expressways, freeways, or parkways. These expressways are high cost facitities designed for heavy traffic flow at relatively high speeds. During the peak traffic periods, when the commuter traffic is heaviest, even these expressways become congested due to the large amount of traffic using them, breaking down the free flow of traffic.

Limited-access roadways generally pass under or over the city streets which make up the remainder of an arterial street system. Traffic seeking to enter an expressway is routed onto it via an entrance ramp from an adjacent frontage road which may be an arterial street of the system. The expressway traffic is generally moving at a relatively high speed, for example in the range of 50 to 60 miles per hour. When this traffic is heavy, a vehicle attempting to enter it frequently must stop until its driver observes an opening or gap in the expressway traffic into which he can merge. To be able to adequately observe the expressway traffic, the driver of the first vehicle waiting to merge usually finds it necessary to wait near the end of the entrance ramp, adjacent the merging area of the entrance ramp and the expressway. Since the merging vehicle must start from a stand-still, it has to accelerate rapidly to the speed of the expressway traffic. Consequently, a substantial gap in the expressway traffic is necessary to enable the entering vehicle to reach the required speed and to merge safely. When the expressway traffic is heavy, it is frequently necessary for the first vehicle on the entrance ramp to wait for a long period of

time before a suitable gap in the expressway traffic is detected by the driver. As a consequence, a line of vehicles frequently accumulates behind the first vehicle, and this line often grows to such a length that it stretches into the adjacent frontage road and adds to the congestion on it and on the remainder of the arterial street system. The results are that congestion on the expressway and on arterial streets is increased and that drivers seeking to travel faster by means of the expressway must spend considerable time waiting to enter the expressway. Therefore the desired result of the expressway, namely to reduce overall travel time, is not achieved.

Attempts have been made to improve the traffic congestion at expressway entrance ramps by closing selected entrance ramps during certain periods of peak traffic congestion. While this somewhat improves the traffic flow on the expressway itself and avoids lines of waiting vehicles on the local streets adjacent the expressway entrance ramp, it diverts vehicles which otherwise would utilize the expressway onto the arterial streets of the local street system. As a consequence, these vehicles require greater travel time because they are unable to utilize the expressway, and the traffic on the local arterial streets is increased with a resulting increase in congestion there.

Other attempts to improve traffic flow at expressway entrance ramps have included the use of traffic control personnel to signal waiting drivers when to enter the expressway. This simply replaces the judgment of the driver with the judgment of the traffic control personnel. Errors in judgment by the controlling personnel or failure of the waiting driver to heed the signals of the control personnel can result either in an acceptable gap in the expressway traffic being ignored because no driver enters it or in a collision of vehicles in the merging area of the entrance ramp and the expressway because a driver attempts to merge when there is no acceptable gap for him.

SUMMARY OF THE INVENTION

In one aspect, the present invention is a system for controlling the release of vehicles onto a limited-access roadway from an entrance ramp which terminates in a merging area with the roadway. The system is adopted for use with vehicle sensing means of the type which provides an indication of vehicle presence and speed and for use with a signalling means which controls release on the entrance ramp of vehicles heading toward the merging area. The signalling means can be located adjacent the entrance ramp a distance from the merging area, and so the vehicle can accelerate some distance before reaching the merging area. This allows the vehicle to merge into a smaller gap than is possible when the vehicle commences its acceleration in the merging area. The system includes means to detect an acceptable gap in the expressway traffic, and means to control the signal to release a waiting vehicle to enable it to accelerate and reach the merging area at the same time the detected gap is at the merging area.

Another aspect of the invention includes means for inhibiting the release signalling to any additional vehicle on the entrance ramp when a previously released vehicle is stopped in the merging area because its driver has failed to merge into the preceding gap.

A further aspect of the invention includes means for signalling a waiting vehicle to enter the merging area even in the absence of an acceptable gap when the line of cars waiting on the entrance ramp has reached such a great length that it is liable to interfere with the traffic on the frontage road.

An additional aspect of the invention includes means to signal continuously for waiting vehicles on the entrance ramp to enter the merging area when there is an

exceptionally long gap in the expressway traffic or when the expressway traffic is so light that metering of the entering traffic is not required.

A still further aspect of the invention includes means for varying the minimum required acceptable gap length in accordance with a characteristic of the traffic flow on either the entrance ramp or the limited-access roadway.

Yet another aspect of the invention includes means for controlling the time-delay projection of the gap from the point at which it is detected upstream of the merging area to the merging area in accordance with a characteristic of the traffic flow on the roadway.

It is accordingly an object of the present invention to provide an improved system for controlling the merging of traffic onto a limited-access roadway from an entrance ramp.

It is another object of the present invention to provide an improved limited-access-roadway-entrance-ramp control system capable of detecting gaps in the roadway traffic into which a vehicle can fit and of signalling to cars waiting to enter the roadway that an acceptable gap is available.

It is a further object of the present invention to provide a control system to detect a gap in the traffic on a limited-access roadway into which a vehicle can merge from an entrance ramp downstream from the point on the roadway at which the gap is detected and to signal a vehicle waiting on the entrance ramp at a time which will allow the vehicle to accelerate along the entrance ramp to reach the merging area at the junction of the entrance ramp and the roadway when the gap has reached the merging area.

It is yet another object of the present invention to provide such a control system for a limited-access roadway entrance ramp which insures reduction of traffic congestion by overriding the regular operation of the control system during times of light traffic or of long gaps in traffic on the roadway and during times when the line of vehicles on the entrance ramp is so long that it might interfere with normal traffic flow on the frontage road.

These and other objects and advantages will be apparent in the present invention from the following detailed description and claims, particularly when taken in conjunction with the accompanying drawings in which like parts are designated by like numerals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a diagram depicting an entrance ramp leading from a frontage road to a limited-access roadway and depicting in block form a prefered embodiment of the present invention.

FIGURE 2 is a representation, partially in schematic and partially in block form, of a voltage level monitor suitable for use in the embodiment of FIGURE 1.

FIGURE 3 is a schematic diagram of a gap detector suitable for use in the embodiment of FIGURE 1.

FIGURE 4 is a block diagram of a gap projector suitable for use in the embodiment of FIGURE 1.

FIGURE 5 is a block diagram of a signal sequence timer and controller suitable for use in the embodiment of FIGURE 1.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIGURE 1 depicts a roadway **10** forming one side of a limited-access divided roadway, the other side being on the far side of the median strip **12** which is beyond the edge **14** of roadway **10**. Traffic on roadway **10** moves to the right, as shown by the arrow, (where the drive-to-the-right rule prevails), while traffic in the opposite direction travels on the other side (not shown) of the dual roadway. Each side of the divided roadway has several lanes for travel, and roadway **10** is shown by way of example in FIGURE 1 as having three lanes of travel.

Entrance ramp **16** connects the adjacent frontage road **18** to roadway **10**, and cars traveling on frontage road **18** are able to enter roadway **10** by means of entrance ramp **16**, as indicated by the arrow on ramp **16**. By way of example, frontage road **18** might be a part of the arterial street system in a large urban area, while limited-access roadway **10** might be part of an expressway, freeway, or parkway through or approaching the urban area. While frontage road **18** is shown parallel to roadway **10** in FIGURE 1, it might run at an angle to roadway **10**, passing over or under it by means of a bridge or underpass.

A merging area **20** is provided at the end of entrance ramp **16**, where it joins roadway **10**. This merging area **20** enables cars entering the roadway **10** from the entrance ramp **16** to travel for a short time parallel to roadway **10** before actually entering its right-hand lane. As depicted in FIGURE 1, frontage road **18** is provided for one-way travel to the right, as shown by the arrow, and a second lane **22** is provided on frontage road **18**, immediately before the entrance ramp **16**, for the convenience of vehicles turning onto entrance ramp **16** from the frontage road **18**, but such a turning lane might not be provided, and frontage road **18** could be a two-way street.

A control signal **24** is mounted adjacent entrance ramp **16**, at a point about half-way between frontage road **18** and merging area **20**, for example. Control signal **24** might be a standard red-yellow-green traffic light, for example. Alternatively, it might be any other type of traffic control signal or device, such as a gate which rises and falls across entrance ramp **16**.

A number of vehicle sensing means or vehicle detectors monitor the traffic flow on roadway **10**, entrance ramp **16**, merging area **20**, and turning area **22**. As depicted in FIGURE 1, detector **D1** is located at a distance upstream from merging area **20** to monitor the traffic in the right-hand lane of limited-access roadway **10** as the traffic approaches merging area **20** on roadway **10**. Detector **D1** is mounted far enough upstream from merging area **20** to enable use of the output information obtained from it, as is explained hereinafter.

Detector **D1** indicates the passage of each vehicle through its detection zone, and it indicates the speed of vehicles as they pass through its detection zone. Detector **D1** may comprise separate detectors to perform these two functions, or they may be performed by the same detector. The detection zone of detector **D1** is depicted in FIGURE 1 by the outline **D1**, and as shown there it includes a brief stretch of the right-hand lane of roadway **10**. Detector **D1** might be any one of several types which are capable of providing the required signals. For example, it could be a sonic detector, such as that disclosed and claimed in co-pending application Ser. No. 551,692 by Bernard J. Midlock, entitled Sonic Vehicle Detector, filed May 20, 1966, now U.S. Patent 3,362,009 issued Jan. 2, 1968, and assigned to the same assignee as the present invention. Alternatively, detector **D1** could be an inductive loop detector, such as a wire loop and a Model LD–1 Loop Vehicle Detector manufactured by Automatic Signal Division of Laboratory for Electronics, Incorporated, and described in that company's LD–1 Loop Detector Bulletin D–168, copyright 1966 by Laboratory for Electronics, Incorporated, by way of example.

Detector **D2** is mounted in a position to monitor vehicles as they pass through merging area **20**. When a vehicle passes through the detection zone of detector **D2** (indicated by outline **D2** in FIGURE 1) the detector provides an output indicative of the speed of that vehicle, and when a vehicle stops in the detection zone of detector **D2**, the detector provides a continuous output indicative of the presence of that vehicle. Detector **D2** could be any one of several types capable of providing the required signals. By way of examples, it could be either the sonic detector or the inductive loop detector described with reference to detector **D1**. To insure coverage of the entire merging area **20**, two or three detectors might be used in parallel.

Detector D3 is mounted in a position to monitor vehicles on entrance ramp **16** after they have passed signal **24**. Detector D3 is required to give outputs indicative of the passage of vehicles. It need not provide vehicle presence or vehicle speed information; it only is required to provide an indication each time a vehicle passes through its detection zone (shown in FIGURE 1 as outline D3). Detector D3 might be any of several types, for example, it could be a sonic detector or an inductive loop detector, as described above with reference to detector D1. Alternatively, it could be a pressure sensitive vehicle detector embedded in the surface of entrance ramp **16**. One such pressure sensitive vehicle detector is the Model HR manufactured by Automatic Signal Division of Laboratory for Electronics, Incorporated, and described in that company's Model HR and HRD Pressure-Sensitive Vehicle Detectors Bulletin D-161, copyright 1957 by Eastern Industries, Incorporated, predecessor in title to Laboratory for Electronics, Incorporated.

Detector D4 is mounted in a position to monitor vehicles on entrance ramp **16** in front of signal **24**. Detector D5 is mounted in a position to monitor vehicles in turning lane **22**. Detectors D4 and D5 are required to provide indications of the presence of vehicles within their respective detection zones (shown by outlines D4 and D5 respectively in FIGURE 1); but they need not provide vehicle speed information. By way of example, detectors D4 and D5 could each be either a sonic detector or an inductive loop detector, as described above with reference to detector D1. To insure coverage of the entire turning lane **22**, two or three detectors might be used in parallel for detector D5.

Detectors D1 through D5 and control signal **24** are connected to the traffic control circuitry, which might be located in a control box adjacent the entrance ramp **16** or alternatively which might be located remote from entrance ramp **16**, by way of examples.

Detector D1 is connected to the input of speed computer **30** and provides to the speed computer **30** signals which are indicative of the speed of vehicles passing detector D1 in the right-hand lane of limited-access roadway **10**. Speed computer **30** develops as its output a voltage which is indicative of the speed of vehicles passing detector D1. This output from speed computer **30** is applied via line **31** as an input to level monitor **32**, which is capable of providing an output indication on any one of a plurality of output lines, represented in FIGURE 1 by line **33**. The particular output line from level monitor **32** which provides an output indication is dependent upon the level of the input voltage applied to the level monitor **32** via line **31** from speed computer **30**. The output from speed computer **30** is also applied by line **31** as an input to level monitor **34** which provides an output when the input applied to it from speed computer **30** indicates that the speed of vehicles passing detector D1 is above a pre-set level, as hereinafter described.

Detector D1 provides to volume computer **36** a signal indicative of the passage of a vehicle past detector D1. Volume computer **36** provides an output voltage which is indicative of the volume of traffic passing detector D1. Thus, the voltage on the output of volume computer **36** is indicative of the number of vehicles per unit time passing detector D1. This output voltage from volume computer **36** is applied by line **37** as an input to level monitor **38** which provides an output when the input applied to it on line **37** from volume computer **36** indicates that the volume of traffic passing detector D1 is below a pre-set level, as hereinafter described.

The outputs from level monitors **34** and **38** are applied as the two inputs of AND gate **40**, which has its output connected via line **42** to signal sequence timer and controller **44**. The output of controller **44** is connected via line **46** to signal **24** to control the operation thereof.

Detector D1 is connected by line **47** to gap detector **48** to provide to the gap detector a signal indicative of the passage of a vehicle past detector D1. Thus, the time between receipt of signals on line **47** by gap detector **48** is indicative of the spacing betwen consecutive vehicles in the right-hand lane of limited access roadway **10**. Gap detector **48** measures the time spacing or "gap" between consecutive vehicles passing detector D1, and when this gap reaches a pre-set minimum acceptable time length, gap detector **48** provides an output on line **49** to gap projector **50**. This output indicates that there has been detected a gap of a duration sufficient for an entering vehicle from entrance ramp **16** to merge into the traffic on the right-hand lane of roadway **10**. After such a minimum acceptable gap has been detected, gap detector **48** continues to measure the gap, and if the gap is great enough to permit additional vehicles to merge onto roadway **10**, gap detector **48** generates a second output signal on line **51** which is passed to gap projector **50**.

Line **47** from detector D1 is connected to gap projector **50** to provide to the gap projector a signal indicative of the passage of a vehicle past detector D1 on roadway **10**. Gap projector **50** also receives as an input the signal on line **49** from gap detector **48** which indicates that there has been detected in the traffic on roadway **10** a gap of a duration sufficient for an entering vehicle from entrance ramp **16** to merge with that traffic. In addition, gap projector **50** is connected by lines **33** to the outputs of level monitor **32**, which indicate the speed of traffic on roadway **10**. This speed is substantially identical with the speed at which the detected gap is moving down roadway **10** from detector D1 toward merging area **20**.

When the vehicle passage signal input on line **47** from detector D1 to gap projector **50** indicates that the start of a gap has reached detector D1, gap projector **50** commences to project a gap-indicating electrical signal through a storage system to simulate or match the passage of the actual gap in traffic flow down roadway **10** toward merging area **20**. If the gap is too short for a vehicle from entrance ramp **16** to merge into the traffic on roadway **10**, then no input is applied on line **49** to gap projector **50** from gap detector **48**, and so the next vehicle passage signal applied on line **47** to gap projector **50** erases the gap-indicating signal. However, if gap detector **48** determines that the gap in traffic flow is long enough for an entering vehicle to merge, then before the gap-indicating signal is erased, gap detector **48** applies a signal on line **49** to gap projector **50**. This signal from gap detector **48** causes gap projector **50** to generate an output at a time when gap projector **50** predicts that the detected gap is passing a "release point" on roadway **10**. The release point, shown in FIGURE 1 as release point R on roadway **10**, is located at a distance upstream from merging area **20**. Control signal **24** signals to a vehicle waiting on entrance ramp **16** to advance toward merging area **20** from a point immediately in front of control signal **24** at the time the detected gap is passing the release point on roadway **10**. As a result, the vehicle reaches merging area **20** and merges onto roadway **10** with substantial speed at the same time the detected gap is passing the merging area.

The output from gap detector **50**, which occurs when the detected gap is passing the release point on roadway **10**, is applied by line **52** to the first signal input of INHIBITED-AND gate **53** which passes it to signal sequence timer and controller **44**. If the detected gap is of great enough length for more than one vehicle to enter the traffic on roadway **10**, then gap detector **48** applies an input on line **51** to gap projector **50**, and the gap projector is enabled to generate an output on line **54** at the time gap projector **50** predicts that the long duration gap is passing the release point on roadway **10**. This second output from gap projector **50** is applied by line **54** as an input to signal sequence timer and con-

troller **44**. Controller **44** then causes control signal **24** to continuously signal to vehicles on entrance ramp **16** to advance to merging area **20** so long as this long duration gap is passing the release point.

Vehicle detector D2 supplies to speed computer **56** an input indicative of the speed of cars passing through merging area **20**. Speed computer **56** generates an output voltage from this input and applies this output voltage by line **57** to level monitor **58**. Level monitor **58** has a plurality of output lines, indicated in FIGURE 1 by line **59**. All of the output lines **59** from level monitor **58** are connected to gap detector **48**. The particular output line from level monitor **58** which supplies an indication to gap detector **48** at any given time is determined by the speed of vehicles which have passed through the detection zone of vehicle detector D2 just prior to that time. This information is interpreted by gap detector **48** as indicative of the ease with which cars from entrance ramp **16** are merging into the traffic on roadway **10**. Based on this information, gap detector **48** adjusts the required duration of the gap in traffic on roadway **10** which must be measured before outputs are supplied on lines **49** and **51** from gap detector **48** to gap projector **50**.

During the time that a vehicle is within the detection zone of vehicle detector D2, detector D2 supplies an input to timer **60**. If this input to timer **60** is of a long duration, it indicates that a vehicle has stopped in merging area **20**, rather than entering a gap in the traffic on roadway **10**. When this occurs, timer **60** generates an output which is applied to the inhibit input of INHIBITED-AND gate **53** and to the inhibit input of INHIBITED-AND gate **62**.

Vehicle detector D3, which is located in a position to detect vehicles on entrance ramp **16** just after they have passed control signal **24**, is connected by line **64** to controller **44**.

Vehicle detector D4, which is located in a position to detect vehicles on entrance ramp **16** just in front of control signal **24**, generates a signal when a vehicle is within its detection zone. This signal is applied as an input to the second signal input of INHIBITED-AND gate **53** and to the first signal input of INHIBITED-AND gate **62**. INHIBITED-AND gate **53** has its output connected by line **66** to signal sequence timer and controller **44**.

Vehicle detector D5, which is located in a position to detect vehicles in turning area **22** of frontage road **18**, is connected to timer **68**. Timer **68** has its output connected to the second signal input of INHIBITED-AND gate **62**, the output of which is connected by line **70** to signal sequence timer and controller **44**. Vehicle detector D5 provides a signal to timer **68** when vehicles are within its detection zone. A continuing signal from detector D5 to timer **68** occurs when a vehicle is stopped in turning area **22**. This indicates that the traffic on entrance ramp **16**, waiting to pass control signal **24**, has formed a line which is approaching frontage road **18**. Once this signal from detector D5 has been applied to timer **58** for a long enough time, the timer **68** generates its output which is applied to INHIBITED-AND gate **62**.

Each of the components of the system depicted in FIGURE 1 may be of standard design. Volume computer **36** is required to generate an output voltage indicative of the volume of traffic flow past vehicle detector D1. Numerous such volume computers are known in the art. By way of example, one volume computer suited for this application is disclosed in U.S. Patent No. 3,059,232, issued Oct. 16, 1962, to J. L. Barker and assigned to the same assignee as the present invention. The volume computer there disclosed requires that with each vehicle passing vehicle detector D1 the input line to the volume computer be grounded. This requirement is met by the sonic vehicle detector and by the inductive loop vehicle detector described above with reference to vehicle detector D1.

Similarly, speed computers **30** and **56** are required to provide output voltages indicative of the speed of vehicles passing vehicle detectors D1 and D2 respectively. Suitable speed computers are known in the art. By way of example, one speed computer suitable for this application is disclosed and claimed in the copending application entitled Speed Averaging Circuit by Ludwig Pallat, one of the co-inventors hereof, filed the same date that the present application is filed and assigned to the same assignee as the present invention. The speed computer there disclosed and claimed requires as an input a pulse having a duration which is inversely proportional to the speed of the passing vehicles. The sonic detector and the inductive loop detector described above with reference to vehicle detector D1 satisfy this requirement. As another example, U.S. Patent 3,059,232 issued Oct. 16, 1962, to J. L. Barker, and assigned to the same assignee as the present invention, discloses a speed averaging circuit suitable for use as speed computers **30** and **56** when vehicle detectors D1 and D2 are Doppler radar detectors of the type disclosed in that same patent.

Level Monitors—FIGURE 2

Each of the level monitors **32**, **34**, **38**, and **58** receives a voltage level as an input, and each generates an output on one of a plurality of output lines, with the particular output which is generated dependent upon the level or magnitude of the applied input voltage. A level monitor suitable for this use is depicted in FIGURE 2, although, of course, other level monitors might be utilized. The level monitor of FIGURE 2 is made up of a plurality of identical sections **78**, designated **78***a*, **78***b*, **78***c* . . . **78***n*. Only the first section **78***a* is shown schematically, but the remainder are identical. The number of sections provided for a particular level monitor depends upon the number of output levels into which the input voltage must be divided.

In each section **78**, a source of positive potential, such as +15 volts D.C., is tied to the first end of the fixed resistance of potentiometer **80**, the second end of which is tied to ground. Similarly, a source of negative potential, such as −15 volts D.C., is tied to the first end of the fixed resistance of potentiometer **82** which has its second end tied to ground. The arms of potentiometers **80** and **82** are connected to the two ends of the fixed resistance of potentiometer **84**. The arm of potentiometer **84** is coupled through resistor **86** to the base of NPN transistor **88**, which has its collector tied to the source of positive potential and its emitter coupled through resistor **90** to the source of negative potential. The base of transistor **88** is also connected to the first end of resistor **92**.

Input line **94** to the level monitor represents input line **31**, **37** or **57** of FIGURE 1 and is divided into lines **94***a*, **94***b*, **94***c* . . . **94***n*, connected respectively the inputs of sections **78***a*, **78***b*, **78***c* . . . **78***n*. Within each section **78**, the second end of resistor **92** is connected to the corresponding input line **94** to which the input voltage level is applied.

The emitter of transistor **88** is tied to the base of PNP transistor **96**, which has its collector coupled through resistor **98** to the negative voltage source and its emitter coupled through resistor **100** to the positive voltage source. The emitter of transistor **96** is also coupled through resistor **104** to ground. The collector of transistor **96** is tied to the base of PNP transistor **102** which has its emitter tied to ground. The collector of transistor **102** is connected to the cathode of diode **106**, the anode of which is tied to the source of negative potential. Capacitor **108** is coupled between the base and the emitter of transistor **102** to filter out high frequency noise.

The collector of the transistor **102** in each section **78** is connected to one side of the coil of a corresponding

relay **110***a*, **110***b* . . . **110***n*, the other side of which is tied to the source of negative potential. Each relay **110** has contacts made up of moving contact or armature **112**, normally-closed contact **14**, and normally-open contact **116**. Armature **112***a*, associated with section **78***a*, is tied to ground. Normally-closed contact **114***a* is connected to output line L1, which signifies that the output voltage applied to the level monitor is within the first level range. Normally-open contact **116***a* is tied to armature **112***b* of the next section **78***b*. Normally-closed contact **114***b* is tied to output line L2, which signifies that the input voltage is within the second level range. Normally-open contact **116***b* is tied to armature **112***c* of section **78***c*. Similarly, each normally-closed contact **114***n* is tied to an output line LN, and each normally-open contact **116** (*n*−1) is tied to the armature **112***n* of the next section. The last normally-open contact **116***n* is connected to an output line *L*(*N*+1). The output lines *L*1−*L*(*N*+1) make up the output lines from the level monitor, such as lines **33** and **59** (FIGURE 1).

With no input applied to line **94**, the emitter of each transistor **88** is slightly negative, and each transistor **96** is on. Therefore, each transistor **102** is off, and each relay coil **110** is isolated from ground. Since relay coil **110***a* is deenergized, armature **112***a* applies ground through normally-closed contact **114***a* to output line L1.

In each section **78**, potentiometers **80**, **82** and **84** determine the input voltage level required to cause energization of the corresponding relay coil **110**. By way of example, if a level monitor is required to provide outputs indicative of speed over a speed range of zero m.p.h. to 100 m.p.h. in increments of ten m.p.h., then nine sections **78***a* through **78***i* are utilized. Each potentiometer **80** is set so that the voltage on its arm represents zero m.p.h., and each potentiometer **82** is set so that the voltage on its arm represents 100 m.p.h. Then the arm of potentiometer **84***a* in section **78***a* is set to a voltage such that, when the input applied to line **94** is a voltage level representing 10 m.p.h., transistor **88***a* conducts more heavily, turning transistor **96***a* off and transistor **102***a* on. This energizes relay coil **110***a*. Similarly, potentiometer **84***b* is adjusted so that when the input applied to line **94** is a voltage level representing 20 m.p.h., relay coil **110***b* is energized. The corresponding potentiometers **84***c* through **84***i* are each adjusted so that the corresponding relay coils **110***c* through **110***i* are energized at 30 m.p.h., 40 m.p.h., etc., through 90 m.p.h.

Ground is applied to output line L1 when the input voltage on line **94** indicates a speed in the range from zero m.p.h. to 10 m.p.h.; ground is applied to output line L2 when the input voltage indicates a speed from 10 m.p.h. to 20 m.p.h., etc. For a speed between 80 m.p.h. and 90 m.p.h., ground is applied on output line L9, tied to normally-closed contact **114***i*. For a speed in excess of 90 m.p.h., ground is applied on output line L10, tied to normally-open contact **116***i*. This, of course, is only an illustrative example, and the number of sections **78** and the settings of the potentiometers **84** are selected to divide the input voltage into the required number of input level ranges and to provide indications on lines L1, etc., to meet the requirements of the particular application. While this illustrative example considers an input voltage indicative of vehicle speed in miles per hour, other inputs can, of course, be provided. Thus, such a level monitor can divide traffic volume information into vehicle per hour ranges, for example.

Thus, for example, level monitor **32**, which provides speed level indications from speed computer **30** to gap projector **50**, might include nine stages having ten output lines, L1 through L10, as described in the above illustrative example. Level monitor **34** requires only a single stage **78** to provide an indication from speed computer **30** to AND gate **40** when the speed of vehicles passing detector D1 is above a pre-set minimum level. In that single stage **78**, the normally-closed relay contact **114** is not connected to anything, while the normally-open contact **116** is tied to the output line, providing the signal from the level monitor **34** to AND gate **40**. The potentiometer **84** is adjusted so that an output is provided from normally-open contact **116** when the speed of vehicles in the right-hand lane of roadway **10** is above a pre-set minimum level.

Level monitor **38** provides a signal to AND gate **40** when the volume computer **36** output indicates that the volume of traffic in the right-hand lane of roadway **10** is below a pre-set maximum level. Thus, level monitor **38** requires only a single section **78**. The output line from monitor **38** to AND gate **40** is connected to the normally-closed relay contact **114**, and the potentiometer **84** is adjusted so that ground is applied to this output line so long as the input on line **37** to level monitor **38** from volume computer **36** indicates that the volume of traffic in the right-hand lane of roadway **10** is below the pre-set maximum level.

Level monitor **58** provides to gap detector **48** indications of the speed of traffic passing through the detection zone of detector D2 in merging area **20**. By way of example, these speeds might be divided into four level ranges. Thus, three sections **78** are required for level monitor **58**. The potentiometers **84** in each of the three sections are adjusted so that the output changes from output line L1 to output line L2 to output line L3 to output line L4 as the speed indication from speed computer **56** increases to show that the speed of vehicles passing through merging area **20** falls within the corresponding ranges.

Gap Detector—FIGURE 3

FIGURE 3 depicts a circuit suitable for use as gap detector **48**. Gap detector **48** receives an input on line **47** from vehicle detector D1 each time a vehicle passes detector D1 in the right-hand lane of roadway **10**. Gap detector **48** also receives inputs on lines **59** from level monitor **58** which indicate the range of speed of vehicles passing through the detection zone of detector D2 in merging area **20** as the vehicles pass from access road **16** to merge into the traffic on roadway **10**. The speed at which vehicles pass through the merging area **20** is indicative of the ease with which the merging is performed. Thus, it indicates whether the gap in the traffic on roadway **10** is of sufficient length. This speed information is utilized by gap detector **48** to adjust the length of the gap in the traffic on roadway **10** which must be detected before gap detector **48** generates output signals to initiate operation of signal **24** to release a waiting or approaching vehicle, as by a given signal indication for example.

In the embodiment of gap detector **48** depicted in FIGURE 3, the input on line **47** from vehicle detector D1 is applied to the first side of the coil of relay **126**, the second side of which is connected to a suitable source of potential, such as +12 volts D.C. By way of example, the gap detector of FIGURE 3 is suitable for use with a level detector **58** which divides into four speed level ranges, L1, L2, L3 and L4, the information indicative of the speed of vehicles passing through merging area **20**. Level monitor **58** accordingly is made up of three sections, each identical to section **78***a* of FIGURE 2. Should it be desired to divide the speed information from speed computer **56** into more narrow ranges, additional level monitor sections such as section **78***a* are provided.

Each of the four input lines **59** bringing the inputs L1, L2, L3 and L4 from level monitor **58** is connected to one side of a relay coil. Thus, inputs L1, L2, L3 and L4 are associated with relays **128**, **130**, **132** and **134**, respectively, within the gap detector **48**. Each of the relay coils **128**, **130**, **132** and **134** has its other side connected to the source of positive potential.

Each of the relays **126**–**134** has two sets of contacts. Relay **126** is illustrative of these. Relay **126** has a moving

contact or armature **126***a* which operates between normally-closed contact **126***b* and normally-open contact **126***c*. Relay **126** has a second moving contact or armature **126***d* which operates between normally-closed contact **126***e* and normally-open contact **126***f*. Similarly, relays **128–134** each have two armatures **128***a*–**134***a* and **128***d*–**134***d*, respectively, each of which operates between normally-closed contacts **128***b*–**134***b* and **128***e*–**134***e*, respectively, and normally-open contacts **128***c*–**134***c* and **128***f*–**134***f*, respectively.

The armature **126***a* of relay **126** is connected to the first side of resistor **136**. Normally-closed contact **126***b* is tied to the armature **128***a* of relay **128**. Normally-open contact **126***c* is tied to ground. Similarly, armature **126***d* of relay **126** is connected to the first side of resistor **138**. Normally-closed contact **126***e* is tied to armature **128***d* of relay **128**. Normally-open contact **126***f* is tied to ground. Normally-closed contact **128***b* is tied to armature **130***a* of relay **130**. Normally-open contact **128***c* is coupled through resistor **128***g* and rheostat **128***h* to the source of positive potential. Normally-closed contact **128***e* is tied to armature **130***d*. Normally-open contact **128***f* is coupled through resistor **128***i* and rheostat **128***j* to the source of positive potential. Normally-closed contacts **130***b* and **130***e* are tied to armatures **132***a* and **132***d*, respectively. Normally-open contact **130***c* is coupled to the source of positive potential through resistor **130***g* and rheostat **130***h*. Normally-open contact **130***f* is coupled to the source of positive voltage through resistor **130***i* and rheostat **130***j*. In like manner, normally-closed contact **132***b* is tied to armature **134***a*; normally-closed contact **132***e* is tied to armature **134***d*; normally-open contact **132***c* is coupled through resistor **132***g* and rheostat **132***h* to the source of positive potential; and normally-open contact **132***f* is coupled through resistor **132***i* and rheostat **132***j* to the source of positive potential. Normally-closed contacts **134***b* and **134***e* have no connections. Normally-open contact **134***c* is coupled through resistor **134***g* and rheostat **134***h* to the source of positive potential, and normally-open contact **134***f* is coupled through resistor **134***i* and rheostat **134***j* to the source of positive potential. If lever monitor **58** divided the speed information into more than four ranges, then the gap detector of FIGURE 3 would receive additional inputs on lines **59** from the level monitor. In such a case, it would have additional relays such as the relays **128–134**, and the contacts of these additional relays would be added to the chain of relay contacts depicted in FIGURE 3, joining the chain at contacts **134***b* and **134***e*.

The second side of resistor **136** is coupled through resistor **140** to the grid of triode **142**, which by way of example may be one-half of a dual-triode tube. The junction of resistors **136** and **140** is connected to the first plate of capacitor **144**, which has its second plate tied to ground. The cathode of triode **142** is coupled through resistor **146** to ground. The plate of triode **142** is connected to the first side of the coil of relay **148**, which has its other side connected to a source of positive potential such as +120 volts D.C. Relay coil **148** is shunted by capacitor **150**.

Triode **152** which, for example, may be the other side of the same dual-triode tube, has its plate tied to the source of positive potential, its cathode tied to the cathode of triode **142**, and its grid connected to the first side of resistor **154**. The second side of resistor **154** is connected to the plate of triode **142**. The grid of triode **152** is also coupled to ground through resistor **156**, which is shunted by capacitor **158**. Armature **148***a* of relay **148** is tied to the source of positive potential, and normally-open contact **148***b* is connected to output line **49** on which is transmitted output signal **G1**, indicative of the detection by vehicle detector **D1** of a gap of duration sufficient for a vehicle from entrance ramp **16** to merge with the traffic on roadway **10**.

Resistor **138** couples armature **126***d* to an identical dual-triode circuit. Thus, the second side of resistor **138** is coupled through resistor **160** to the grid of triode **162**. The junction of resistors **138** and **160** is connected to the first plate of capacitor **164**, which has its second plate tied to ground. The cathode of triode **162** is coupled through resistor **166** to ground. The plate of triode **162** is tied to the first side of the coil of relay **168**, which has its second side connected to a source of positive potential, such as +120 volts D.C. Relay coil is shunted by capacitor **170**.

Triode **172** has its plate tied to the source of positive potential, its cathode tied to the cathode of triode **162** and its grid coupled through resistor **174** to the plate of triode **172**. The grid of triode **172** is coupled to ground through resistor **176**, which is shunted by capacitor **178**. Armature **168***a* of relay **168** is tied to a source of positive potential, while normally-open contact **168***b* is connected to output line **51**, on which is transmitted output signal **G2**, indicative of the detection by vehicle detector **D1** of a long-duration gap of a length sufficient for more than one vehicle from entrance ramp **16** to merge with the traffic on roadway **10**.

When an input is applied to relay **126** from vehicle detector **D1**, the first side of relay coil **126** is connected to ground, thereby energizing the relay. Similarly, when level monitor **58** applies an input on one of the input lines **59** to one of the relays **128–134**, the first side of that relay coil is connected to ground, thereby energizing the relay. Assume for the moment that no inputs are applied to gap detector **48** from level monitor **58**. Then relays **128–134** are all in their de-energized condition, and so no voltage is applied from armatures **126***a* and **126***d* to the two dual-triode circuits. In such a case, triode **152** conducts because current flowing from the positive voltage source through relay coil **148**, resistor **154** and resistor **156** to ground biases the triode to conduction. Similarly, triode **172** conducts because of current flow through relay coil **168** and resistors **174** and **176**. However, because resistors **154**, **156**, **174** and **176** are very large, the currents flowing through relay coils **148** and **168** are not great enough to energize the relays.

When one of the relays **128–134** is energized, its normally-open contacts close, providing charging paths for capacitors **144** and **164**. As current passes through resistor **136**, the voltage on capacitor **144** increases. This raises the voltage on the grid of triode **142** until that triode commences to conduct. When that happens, the current flowing through relay **148** increases, and the relay is energized, thereby applying voltage from the positive voltage source through armature **148***a* and normally-open contact **148***b* to output line **49** to generate the output signal **G1**. Similarly, current passing through resistor **138** charges capacitor **164** until triode **162** conducts, energizing relay **168** and applying voltage from the positive voltage source through armature **168***a* and normally-open contact **168***b* to output line **51** to generate output signal **G2**.

When the system is in operation, one and only one of the relays **128–134** is energized at all times by one of the inputs **L1–L4** on lines **59** to gap detector **48** from level monitor **58**. The relay which is energized pulls its armatures into contact with their normally-open contacts. This provides charging paths for capacitors **144** and **164** from the positive voltage source, through the rheostats ond resistors associated with the relay and through their normally-open contacts, through normally-closed contacts **126***b* and **126***e*, through armatures **126***a* and **126***d*, and through resistors **136** and **138** to the capacitors **144** and **164**, and to ground. Thus, by way of example, if the speed of vehicles passing through merging area **20** is at a low level, the output voltage from speed computer **56** is low, and so level monitor **58** applies an input **L1** to gap detector **48**. As

a consequence, relay 128 is energized, closing its normally-open contacts.

The rates at which capacitors 144 and 164 charge are determined, respectively, by the settings of rheostats 128*h* and 128*j*. When a vehicle passes vehicle detector D1, relay 126 is energized, and so armatures 126*a* and 126*d* are connected to ground through normally-open contacts 126*c* and 126*f*, respectively. This discharges capacitors 144 and 164. After the vehicle has passed detector D1, relay 126 is de-energized, and armatures 126*a* and 126*d* return to contact with normally-closed contacts 126*b* and 126*e*, respectively, and the charging of capacitors 144 and 164 commences again. Thus, the start of a gap between consecutive vehicles in the right-hand lane of roadway 10 is marked by the commencement of the charging of capacitors 144 and 164.

If the gap is of a long enough time duration, then before relay 126 causes the discharge of capacitor 144, the charge on capacitor 144 increases the voltage on the grid of triode 142 until the triode 142 conducts. This energizes relay 148, causing an output G1 on line 49. Thus, if the gap between vehicles passing detector D1 is of a time length sufficient for a vehicle from entrance ramp 16 to merge with the traffic on roadway 10, relay 148 is energized to provide output G1 on line 49. If this gap continues until it is so long that additional vehicles from ramp 16 could merge with the traffic on roadway 10, then before relay 126 causes the discharge of capacitor 164, the charge on capacitor 164 increases the voltage on the grid of triode 162 until triode 162 conducts. This energizes relay 168, and output G2 is provided on line 51. These outputs G1 and G2 on lines 49 and 51, respectively, are applied by gap detector 48 to gap projector 50 which determines when the gaps have reached the release point R.

Capacitor 144 charges as a function of time. Thus, a gap between vehicles of a minimum time length is required to generate output signal G1. As the speed of vehicles on roadway 10 increases, the distance length of this minimum time length gap increases. Thus, gap detector 48 automatically varies the distance length of the required gap in accordance with the speed of the traffic on roadway 10. This, of course, is modified by the effect of the inputs L1–L4 to gap detector 48.

The speed at which vehicles travel through merging area 20 indicates the ease with which these vehicles are merging into the traffic on roadway 10. If traffic on roadway 10 is of low density and is moving at relatively high speed, then vehicles entering this traffic from entrance ramp 16 pass through merging area 20 at a relatively high speed. However, when the density of the traffic on roadway 10 is greater or the speed of traffic on roadway 10 is lower, vehicles merging into this traffic from entrance ramp 16 passes through merging area 20 at lower speeds.

If the speed at which the vehicles pass through merging area 20 increases, then level monitor 58 removes input L1 applied to gap detector 48 and replaces it with input L2. This de-energizes relay 128, removes resistor 128*g* and rheostat 128*h* from the charging circuit of capacitor 144 and removes resistor 128*i* and rheostat 128*j* from the charging circuit of capacitor 164. Relay 130 is energized and resistor 130*g* and rheostat 130*h* and resistor 130*i* and rheostat 130*j* provide charging paths for capacitors 144 and 164, respectively. Rheostats 130*h* and 130*j* are adjusted to lower settings of resistance then are the corresponding rheostats 128*h* and 128*j*. Consequently, the currents flowing in the charging paths of capacitors 144 and 164 are greater when level detector 58 applies input L2 to gap detector 48 than they are when detector 58 applies input L1 to the gap detector. Therefore, relays 148 and 168 are energized more quickly than before. Thus, the minimum acceptable gap between consecutive actuations of relay 126 by vehicles passing vehicle detector D1 is shortened. Each time a gap of the minimum acceptable duration is detected, relay 148 is energized to generate output signal G1. Each time the detected gap is of a duration great enough to admit more than one vehicle onto roadway 10, as determined by the output level L1–L4 from level monitor 58 to gap detector 48, relay 168 is energized to generate output signal G2.

Should the speed of vehicles passing through merging area 20 increase further, level monitor 58 applies signal L3 to gap detector 50, and so relay 130 is de-energized and relay 132 is energized. This removes resistor 130*g* and rheostat 130*h* from the charging path of capacitor 144 and removes resistor 130*i* and rheostat 130*j* from the charging path of capacitor 164. In place of these, resistors 132*g* and rheostat 132*h* provide a charging path for capacitor 144, while resistor 132*i* and rheostat 132*j* provide a charging path for capacitor 164.

Again, rheostats 132*h* and 132*j* are adjusted to lower settings than their corresponding rheostats 130*h* and 130*j*, and so a higher current flows in the charging paths of capacitors 144 and 164. Thus, shorter gaps are accepted to give outputs G1 and G2. The speed level L4 signal from level monitor 58 to gap detector 50 energizes relay 134 and results in even shorter gaps being accepted.

In the embodiment of gap detector 48 which is depicted in FIGURE 3, the speed indications L1–L4 determine the gap durations required to generate signals G1 and G2 by controlling the resistance in the charging paths of capacitors 144 and 164, respectively. Obviously, equivalent designs could be used. For example, the signals L1–L4 could be used to control bias on triodes 142 and 162 to vary the amount by which the voltage on capacitors 144 and 164 must be increased to cause the triodes 142 and 162 to conduct. Alternatively, signals L1–L4 could vary the supply voltage applied to one end of each of two fixed resistances which have their other ends connected respectively to relay contacts 126*b* and 126*e*. Other equivalent designs could be used.

Gap Projector—FIGURE 4

Gap projector 50 receives from vehicle detector D1 an indication on line 47 whenever a vehicle is not within the detection range of detector D1. This input is indicative of the passage of a gap between vehicles past detector D1. If that gap is of a length sufficient to allow a vehicle from entrance ramp 16 to merge into it on roadway 10, gap projector 50 receives signal G1 on line 49 from gap detector 48. Gap projector 50 also is connected by lines 33 to level monitor 32 to receive signals which are indicative of the speed at which traffic is travelling in the right-hand lane of roadway 10. From this information, gap projector 50 predicts when the gap has reached release point R. Gap projector 50 then generates on line 52 an output signal G1′ having a duration equal to the duration of the detected gap. If gap detector 48 indicates that the detected gap is of a great enough duration to allow more than one vehicle to merge into the traffic on roadway 10, then it transmits signal G2 on line 51 to gap projector 50, and gap projector 50 provides on line 54 an output G2′ indicative of this long duration gap.

FIGURE 4 depicts circuitry suitable for use as gap projector 50. Input line 47 to the gap projector of FIGURE 4 couples vehicle detector D1 to the first plate of capacitor 188 which has its second place tied to the anode of diode 190. The cathode of diode 190 is connected to the input of monostable multivibrator or one-shot 192. One-shot 192 has its output connected to the set input of flip-flop 194. The second plate of capacitor 188 is also connected to the cathode of diode 196, which has its anode tied to the input of one-shot multivibrator 198. The output of one-shot 198 is tied to the reset input of flip-flop 194. The first plate of capacitor 188 is coupled through resistor 199 to a source of positive voltage such as +12 volts D.C.

Shift register 200 is made up of a number of interconnected stages 200*a*–200*x*, and the set output of flip-flop 194 is tied to the set input of the first stage 200*a*. The reset input to each stage of shift register 200 is connected to the output of one-shot 198. Shift register 202 is made up of a large number of stages, 202*a*–202*z*, 202A–202Z. The output of each stage of shift register 200 is coupled to the set input of the corresponding stage of shift register 202 through AND gates 204. Thus, stage 200*a* has its output connected to the first input of AND gate 204*a*, the output of which is connected to the set input of stage 202*a*; the output of stage 200*b* is connected to the first input of AND gate 204*b* which has its output tied to the set input of stage 202*b*; etc. Thus, for each stage in shift register 200 there is a corresponding AND gate 204 and a corresponding stage in shift register 202. Shift register 202, however, contains more stages than does shift register 200. The second input of each AND gate 204 is connected to input line 49 which brings signal G1 from gap detector 48 to gap projector 50.

Controlled multivibrator 208 has ten input lines 33 bringing the ten inputs L1–L10 from the corresponding lines 33 of level monitor 32. Level monitor 32 is of the type described above with reference to FIGURE 2, and, in this representative example, contains nine additional sections, each identical to section 78*a*. As described above, one and only one of the outputs L1–L10 from level monitor 32 is present at any one time, and that output which is present is represented by ground potential on its output line. Controlled multivibrator 208 is a free-running multivibrator, the free-running rate of which is dependent upon which one of the inputs L1–L10 from level monitor 32 is at ground potential.

The output of multivibrator 208 is tied to shift register 202 to provide the shift pulses for the shift register 202. The output of multivibrator 208 is also connected to the signal input of INHIBITED-AND gate 210, the output of which is tied to shift register 200 to provide the shift pulses to shift register 200. The inhibit input of INHIBITED-AND gate 210 is connected to input line 49 which brings the input signal G1 from gap detector 48.

The output of shift register stage 202*x* is connected to the first input of AND gate 206*a* which has its other input tied to the input line 33 which brings signal L10 from level monitor 32. The output of shift register stage 202A is connected to the first input of AND gate 206*b* which has its other input tied to the input line 33 which brings signal L9 from level monitor 32. The output of shift register stage 202W is connected to the first input of AND gate 206*i* which has its other input tied to the input line 33 which brings signal L2 from level monitor 32. The output of shift register stage 202Z is connected to the first input of AND gate 206*j* which has its other input tied to the input line 33 which brings signal L1 from level monitor 32. Similarly, six other stages of shift register 202 between stages 202A and 202W have their outputs connected to inputs of AND gates 206*c*–206*h*, respectively. These six other gates 206*c*–206*h* have their second inputs connected to the input lines 33 bringing signals L8–L3 respectively, from level monitor 32. The output of each of the AND gates 206 is connected to OR gate 207. The output of OR gate 207 is tied to output line 52 on which output signal G1′ is transmitted from gap projector 50 to INHIBITED-AND gate 53 (FIGURE 1) to signify that the detected gap has reached release point R.

Input line 51 brings the input signal G2 from gap detector 48 to gap projector 50 where it is applied to the set input of flip-flop 216. The set output of flip-flop 216 is connected to the first input of AND gate 218, which has its second input connected to the output line 52. The output of AND gate 218 is connected to the output line 54 on which the output signal G2′ is transmitted to signify that the gap which has reached release point R has a duration long enough to let more than one car from entrance ramp 16 merge with the traffic on roadway 10.

Output line 54 is also connected to the input of inverting amplifier 222, which has its output connected to the first plate of capacitor 224. The second plate of capacitor 224 is connected to the anode of diode 226 and to the cathode of diode 228. The cathode of diode 226 is tied to the reset input of flip-flop 216. The anode of diode 228 is coupled to ground through resistor 230. The anode of diode 226 is coupled to ground through resistor 232.

The speed at which vehicles are traveling on roadway 10 as they pass vehicle detector D1 determines which one of the inputs L1–L10 is applied via the associated line 33 from level monitor 32 to controlled multivibrator 208. The pulse rate of the output from controlled multivibrator 208 is thus dependent upon the level of the output voltage from speed computer 30 as monitored by level monitor 32. If the speed of vehicles passing vehicle detector D1 is low, then the output voltage from speed computer 30 is low, and so level monitor 32 applies signal L1 to controlled multivibrator 208. This causes multivibrator 208 to pulse at a low repetition rate. If the speed of vehicles on roadway 10 passing vehicle detector D1 increases, then the output voltage from speed computer 30 to level monitor 32 increases, and level monitor 32 removes signal L1 and replaces it with a higher level signal such as signal L2. As a consequence, the repetition rate of controlled multivibrator 208 increases.

When a vehicle is within the detection zone of vehicle detector D1, ground is applied to input line 47 of gap projector 50. Thus, each gap between vehicles is indicated on input line 47 by the removal of ground. The resulting positive-going pulse passes through capacitor 188 and diode 190 to trigger one-shot multivibrator 192. The output pulse of one-shot 192 sets flip-flop 194. The set output of flip-flop 194 sets shift register stage 200*a* to signify the presence of a gap at vehicle detector D1. The first pulse from multivibrator 208 after stage 200*a* is set shifts the set condition from stage 200*a* to stage 200*b*. Since flip-flop 194 is still in its set condition, stage 200*a* remains set. With each succeeding pulse from multivibrator 208, the set condition shifts to the next succeeding stage of shift register 200, and the set output of flip-flop 194 re-introduces a set condition at the first stage 200*a*.

If the gap is of a duration too short to permit a vehicle to merge into the traffic on roadway 10 from entrance ramp 16, then input signal G1 is never applied from gap detector 48 to gap projector 50 on line 49. When a vehicle passes vehicle detector D1 to end the gap, ground is applied on line 47, and the resulting negative-going pulse passes through capacitor 188 and diode 196 to trigger one-shot multivibrator 198. The output of one-shot 198 resets flip-flop 194 and resets each stage of shift register 200 so that the entire shift register is reset simultaneously. When that vehicle has passed from the detection zone of vehicle detector D1, another gap occurs and ground is removed from input line 47. As a consequence, one-shot 192 sets flip-flop 194 which applies a signal to the set input of shift register stage 200*a*. Again with each pulse from multivibrator 208, the set condition is transferred to the next succeeding shift register stage and flip-flop 194 retains stage 200*a* in its set condition. If this gap is of a duration sufficient to permit a vehicle from entrance ramp 16 to merge into the traffic on roadway 10, then gap detector 48 applies signal G1 to gap projector 50 by means of input line 49. Signal G1 is applied as an enabling input to each AND gate 204.

The AND gates 204 read the information from shift register 200 and write it into the corresponding stages of shift register 202. Thus, if the set condition of shift register 200 has progressed, for example, to stage 200*g* by the time that input signal G1 is applied on input line 49, then each of the shift register stages 200*a*–200*g* is in its set condition at that time, while the succeeding stages 200*h*, etc., are not. AND gates 204*a*–204*g* pass

this set condition to the set inputs of shift register stages **202***a*–**202***g*. AND gates **204***h*, etc. are also enabled by signal **G1**, but shift register stages **200***h*, etc. are not set, and so no set input is applied to shift register stages **202***h*, etc. Each succeeding pulse from multivibrator **208** transfers the gap indication to the succeeding stages of shift register **202** until the set condition reaches the last stage **202Z**.

Input line **49** is connected to the inhibit input of INHIBITED-AND gate **210** so that pulses from multivibrator **208** do not shift the information within shift register **200** after signal **G1** is received. Consequently, after input signal **G1** is received, the output of stage **200***a* remains set, and so it continues to apply a set input to stage **202***a* at each pulse from multivibrator **208**. When the next vehicle passes vehicle detector **D1**, ground is again applied on input line **47**, and one-shot **198** resets flip-flop **194** and each of the stages of shift register **200**. At that time the signal **G1** is also removed from input line **49**. As a consequence, the set input is no longer applied to shift register **202***a* and so, with each succeeding pulse from multivibrator **208**, the reset condition of the shift register is transferred to the succeeding stages, marking the end of the gap.

The speed of vehicles passing detector **D1** determines which input **L1**–**L10** is applied via lines **33** from level monitor **32** to gap projector **50**. Whichever input **L1**–**L10** is present enables its corresponding AND gate **206**. When the gap indication passing through shift register **202** reaches the stage which has its output tied to the enabled AND gate **206**, a signal passes from that AND gate **206**, through OR gate **207** to line **52** to indicate that the gap has reached release point R on roadway **10**. This output signal **G1'** on line **52** continues so long as the shift register stage within shift register **202** which is providing it continues in its set condition. Thus, it continues until the reset condition has been shifted to that stage of shift register **202**, following the termination of the gap. Accordingly, the gap indication output **G1'** on line **52** exists for the same length of time that the gap itself exists, as indicated by the potential on input line **47** from detector **D1**.

If the gap is of a duration sufficient to permit more than one vehicle from entrance ramp **16** to merge into it on roadway **10**, then signal **G2** is generated by gap detector **48** and is applied by line **51** to gap detector **50**. This sets flip-flop **216**, and the set output of flip-flop **216** enables AND gate **218**. Consequently, when the output signal **G1'** is provided on output line **52**, it is applied to AND gate **218**, causing AND gate **218** to generate output signal **G2'** on output line **54**. The resulting negative pulse from inverting amplifier **222** is passed to ground through diode **228** and resistor **230**. After output signal **G1'** terminates, indicating that the end of the gap has reached release point R, the input is removed from AND gate **218**, and so output signal **G2'** ends. This results in a positive-going pulse passing from inverting amplifier **222** through capacitor **224** and diode **226** to reset flip-flop **216**.

With gap detector **50** operating in this manner, the number of stages in shift register **202** through which the gap indication passes, commencing at stage **202***a*, is proportional to the distance on roadway **10** from vehicle detector **D1** to release point R.

When traffic on roadway **10** is travelling at a high speed and is closely-spaced, it is likely that traffic through merging area **20** is travelling at a low speed. In such a situation, level monitor **58** applies signal **L1** to gap detector **48**. This requires a long-duration gap between vehicles passing vehicle detector **D1** before gap detector **48** generates signal **G1**. The high speed of vehicles passing vehicle detector **D1** results in level monitor **32** applying signal **L10** to gap projector **50** to cause a high output rate from controlled multivibrator **208**. Consequently, the gap indication is shifted through shift register **200** at a rapid rate. Shift register **200** must contain enough stages to permit storage of the entire gap at this highest repetition rate, up until signal **G1** is received.

Shift register **202** must contain enough stages to permit delay of the gap signal for the time required for the gap to reach release point R. As the speed of vehicles passing vehicle detector **D1** increases, the speed with which the gap reaches release point R increases. However, the repetition rate of controlled multivibrator **208** also increases, and so the gap signal is passed through shift register **202** more rapidly. Thus, the number of stages required in shift register **202** is dependent upon the distance which vehicle detector **D1** is located from merging area **20**. While FIGURE 4 indicates that shift register **200** includes stages **200***a*–**200***x* and that shift register **202** includes stages **200***a*–**200***z*, this is only a representation intended to indicate that a large number of stages exist, and it is not intended in any way to indicate the exact number of stages in either shift register.

The gap indication within shift register **202** is not reset when a vehicle indication on input line **47** triggers one-shot multivibrator **198**. Only flip-flop **194** and shift register **200** are reset. At the next pulse from controlled multivibrator **208**, shift register stage **202***a* is reset, and with each succeeding pulse from multivibrator **208** this reset condition passes to a succeeding stage within shift register **202**, marking passage of the end of the gap along roadway **10**. When the vehicle indication ends, the signal on line **47** triggers one-shot **192**, which sets flip-flop **194**, to start the next gap indication through shift register **200**. If this gap is found to be long enough to permit merger of a vehicle into it, signal **G1** is again applied to AND gates **204** to transfer the gap indication from shift register **200** to shift register **202**. Thus, passage of two or more gaps along roadway **10** can be predicted simultaneously by gap projector **50**.

Controlled multivibrator **208** might be any conventional design of free-running multivibrator having a repetition rate determined by which one of the inputs **L1** through **L10** is applied to it. By way of example, the controlled multivibrator **208** could be a standard free-running multivibrator with each input line **L1** through **L10** connected to a corresponding relay. Then application of ground potential by level monitor **32** to one of the input lines **L1**–**L10** energizes that corresponding relay to place a corresponding resistor in the timing circuit of the free-running multivibrator. Alternatively, solid state switching could be utilized in place of relays.

Signal Sequence Timer and Controller—FIGURE 5

Signal sequence timer and controller **44** receives input signals on lines **42**, **54**, **64**, **66** and **70** from the vehicle detectors and control circuitry and, in response to these signals, controller **44** applies voltages via line **46** to control signal **24** to cause signal **24** to indicate to vehicles waiting on entrance ramp **16** when they should proceed toward merging area **20**. For example, controller **44** can be an electro-mechanical device, made up of appropriate timing and gating circuitry and a stepping switch. Alternatively, controller **44** can comprise electronic switching circuits which provide the required sequence of signals.

The particular design of controller **44** is dependent in part upon the type of traffic control signal **24** utilized. FIGURE 5 depicts an electronic controller which is suitable for use as signal sequence timer and controller **44** when signal **24** is of the well-known red, yellow, green traffic light type and which is made up of standard components.

Input line **42** from the output of AND gate **40** (FIGURE 1) to signal sequence timer and controller **44** is connected to the first input of OR gate **238** which has its other input tied to line **54** on which signal **G2'** is transmitted by gap projector **50**. Input line **42** is also tied to the first input of OR gate **240**. Line **66** from the output of INHIBITED-AND gate **53** (FIGURE 1) is connected to the second input of OR gate **240**. The output of OR

gate **240** is connected to the first input of AND gate **246** which has its output tied to the first input of OR gate **248**. Line **70** from the output of INHIBITED-AND gate **62** (FIGURE 1) is connected to the first input of AND gate **250** within controller **44**. The output of AND gate **250** is tied to the input of time delay circuit **252** which has its output connected to the second input of OR gate **248**. The output of OR gate **248** is connected to the reset input of flip-flop **254** and to the set input of flip-flop **256**.

The output of OR gate **238** is tied to the cathode of diode **257** which has its anode connected to the input of one-shot multivibrator **258**. The output of one-shot **258** is connected to the first input of OR gate **259**. Line **64** from detector D3 is connected to the input of inverting amplifier **260** which has its output tied to the second input of OR gate **259**. The output of OR gate **259** is connected to the first signal input of INHIBITED-AND gate **261** which has its inhibit input tied to the output of OR gate **238**. The output of INHIBITED-AND gate **261**, is connected to the reset input of flip-flop **256** and to the set input of flip-flop **262**.

The set output of flip-flop **254** is connected to control signal **24** by line **264** to provide the red or "stop" indication for the control signal **24**. The set output of flip-flop **256** is connected to control signal **24** by line **266** to provide the green or "go" indication for the control signal **24**. The set output of flip-flop **262** is connected to control signal **24** by line **268** to provide the yellow or "clearance" indication for the control signal **24**. These output lines **264**, **266** and **268** from flip-flops **254**, **256** and **262**, respectively, constitute output line **46**, shown in FIGURE 1 connecting controller **44** to control signal **24**.

Line **264** from the set output of flip-flop **254** is connected to the input of timer circuit **270**, which has its output tied to the second input of AND gate **246** and to the second input of AND gate **250**. Line **266** from the set output of flip-flop **256** is connected to the second signal input of INHIBITED-AND gate **261** and to the first input of AND gate **274**. AND gate **274** has its output connected to the input of time delay circuit **276**, the output of which is connected to the third input of OR gate **259**. Line **268** from the set output of flip-flop **262** is connected to the input of timer circuit **278** and to the input of timer circuit **280**. The output of timer circuit **278** is applied to the first input of AND gate **282**. The output of timer circuit **280** is connected to the first signal input of INHIBITED-AND gate **284**. The outputs of gates **282** and **284** are connected to the two inputs of OR gate **286**. The output of OR gate **286** is tied to the input of one-shot **287** which has its output connected to the set input of flip-flop **254** and to the reset input of flip-flop **262**.

Input lines **66** and **70** are connected to the two inputs of OR gate **288**, which has its output tied to the set input of flip-flop **290**. The set output of flip-flop **290** is connected to the second signal input of INHIBITED-AND gate **284** and to the signal input of INHIBITED-AND gate **291**. The reset input of flip-flop **290** is tied to the output of one-shot **287**. The output of OR gate **238** is connected to the set input of flip-flop **292** which has its reset input tied to the output of one-shot **287** and its set output connected to the second input of AND gate **282** and to the inhibit of INHIBITED-AND gate **284**. Input line **70** is connected to the inhibit input of INHIBITED-AND gate **291**, which has its output tied to the second input of AND gate **274**.

OPERATION OF THIS PREFERRED EMBODIMENT

The control system of the present invention is capable of adapting its operation to meet the varying traffic conditions which occur on limited-access roadway **10**, entrance ramp **16**, and frontage road **18**. Its primary manner of operation is used when traffic on roadway **10** is heavy and the number of vehicles on entrance ramp **16** waiting to enter roadway **10** from frontage road **18** is high, for example, during the periods in the morning and evening when the commuter traffic is heavy. Under such conditions, volume computer **36** provides an output to level monitor **38** which indicates that the volume of traffic passing vehicle detector D1 is high. As a consequence, level monitor **38** does not provide an output to AND gate **40**, and so no input on line **42** is provided to signal sequence timer and controller **44**.

Gaps between consecutive vehicles in the right-hand lane of roadway **10** are detected by gap detector **48**. Speed computer **56** provides to level monitor **58** a voltage indicative of the speed with which vehicles have been passing through merging area **20**. As determined by this voltage level, level monitor **58** provides one of the signals L1–L4 to gap detector **48**, thereby grounding the associated relay **128–134** within the gap detector. During the gaps in the traffic on roadway **10**, the timing circuit associated with relay **148** within gap detector **48** commences to time. If another vehicle comes within the detection zone of vehicle detector D1 before relay **148** is energized, then energization of relay **126** within gap detector **48** terminates the timing operation by discharging capacitor **144** through resistor **136**, armature **126***a*, and normally-open contact **126***c* to ground. When a gap passes detector D1 with a duration great enough to permit a vehicle from entrance ramp **16** to merge onto roadway **10**, the voltage on capacitor **144** increases until triode **142** conducts. As a result, relay **148** is energized, generating signal G1 which is transmitted to gap projector **50** on line **49**. The time required for the voltage on capacitor **144** to cause initiation of signal G1 is, of course, dependent upon which input L1–L4 is applied to gap detector **48** from level monitor **58**.

The signal from vehicle detector D1 is also applied to gap projector **50** via line **47**. As a result, flip-flop **194** within gap projector **50** sets shift register stage **200***a*. Pulses from controlled multivibrator **208** within gap projector **50** shift this set condition through the consecutive stages of shift register **200**. The speed at which controlled multivibrator **208** causes this set condition, indicative of the detected gap, to be shifted through shift register **200** is dependent upon the speed at which vehicles have been passing vehicle detector D1. This vehicle speed is converted to a voltage by speed computer **30**, and the voltage is applied to the input of level monitor **32** which provides one of the indications L1–L10 to controlled multivibrator **208**, dependent upon the level of the voltage from speed computer **30**. The repetition rate of controlled multivibrator **208** is dependent upon which one of the indications L1–L10 is applied to the controlled multivibrator from level monitor **32**. Accordingly, the rate at which the gap indication is shifted through shift register **200** is dependent upon the speed of traffic on roadway **10**.

When gap detector **48** applies signal G1 to gap projector **50** on line **49**, the AND gates **204** transfer the gap indication from shift register **200** to shift register **202**. The shift pulses from multivibrator **208** are blocked by INHIBITED-AND gate **210**, and so there is no signal applied to the shift input of shift register **200**. Shift register stage **200***a* remains in its set condition as long as the gap exists, and this set output from stage **200***a* is passed through AND gate **204***a* to the set input of shift register stage **202***a*.

The entire gap indication from shift register **200** is transferred to shift register **202**. Pulses from multivibrator **208** cause this gap indication to be shifted through the consecutive stages of shift register **202***a*. With each shift of information through the stages of shift register **202**, the set signal from stage **200***a* through AND gate **204***a* causes stage **202***a* to remain in its set condition, and so the gap indication is continuously fed into shift register **202**, so long as the gap continues. Once the gap ends, signal G1 is terminated, removing the enabling inputs

from AND gates **204**, and one-shot **198** resets flip-flop **194** and resets each stage of shift register **200**. The next pulse from multivibrator **208** causes shift register stage **202***a* to resume its reset condition, and with succeeding pulses from multivibrator **208** the succeeding stages of shift register **202** are reset, indicating the passage of the end of the gap through the shift register **202**.

The gap indication continues to progress through the consecutive stages of shift register **202** with each pulse from controlled multivibrator **208**. That input signal **L1–L10** which is present on line **33** enables its associated AND gate **206**. When the set condition indicative of the leading edge of the gap reaches the shift register stage which is connected to the enabled AND gate **206**, output signal **G1'** is initiated on line **52**. This signal is applied to INHIBITED-AND gate **53**. If no vehicle is stopped within the detection zone of detector **D2** in merging area **20** and if a vehicle is waiting within the detection zone of detector **D4** in front of control signal **24**, then INHIBITED-AND gate **53** applies signal **G1'** on line **66** to signal sequence timer and controller **44**.

The signal **G1'** on line **66** passes through OR gate **240** to the first input of AND gate **246**. If control signal **24** is indicating red or "stop," then flip-flop **254** is set, and this set output is applied to the input of timer **270** which times a minimum duration for the red indication. Once the minimum red duration has passed, timer **270** applies an input to AND gate **246**. Coincidence of the two inputs to AND gate **246** results in a signal passing from AND gate **246** through OR gate **248** to reset flip-flop **254** and to set flip-flop **256**. As a consequence, the red or "stop" indication on line **264** from the set output of flip-flop **254** is terminated, and it is replaced with a green or "go" indication on line **266** from the set output of flip-flop **256**. Thus, control signal **24** indicates green or "go" to release the vehicle waiting on entrance ramp **16** in front of the control signal **24**.

The vehicle on entrance ramp **16** then proceeds toward merging area **20** to merge onto roadway **10**. When that vehicle passes over detector **D3** on its way toward merging area **20**, ground is applied on line **64** to the input of inverting amplifier **260** within controller **44**. Inverting amplifier **260** then applies a signal through OR gate **259** to the first signal input of INHIBITED-AND gate **261**. The second signal input of INHIBITED-AND gate **261** is energized by the green indication on line **266** from the set output of flip-flop **256**. There is no signal applied to the inhibit input of INHIBITED-AND gate **261**, and so the INHIBITED-AND gate applies a signal to the reset input of flip-flop **256** and to the set input of flip-flop **262**. As a consequence, the green or "go" indication on line **266** from the set output of flip-flop **256** is terminated, and it is replaced by a yellow or "clearance" indication on output line **268** from the set output of flip-flop **262**.

The input **G1'** on line **66**, which initially caused the change of the control signal from red to green, also passes through OR gate **288** to set flip-flop **290**. The set output of flip-flop **290** is applied to the first signal input of INHIBITED-AND gate **284**. The set output from flip-flop **262**, which provides the yellow indication for control signal **24**, is applied to the input of timer **280** which times a short duration yellow or "clearance interval." When timer **280** has timed out, a signal is applied from it to the second input of INHIBITED-AND gate **284**. Since flip-flop **292** is reset, there is no signal applied to the inhibit input of INHIBITED-AND gate **284**. Therefore, a signal from INHIBITED-AND gate **284**, passes through OR gate **286** to trigger one-shot **287** which resets flip-flops **262** and **290** and sets flip-flop **264**. Consequently, the yellow or "clearance" indication from the set output of flip-flop **262** is terminated, and the red or "stop" indication is again provided by the set output of flip-flop **254**. Thus, the control signal **24** is cycled from red to green to yellow and back to red to signal to the waiting vehicle that it should proceed on entrance ramp **16** through merging area **20** to merge with the traffic on roadway **10**.

Vehicle detector **D1** applies a signal to gap detector **48** and to gap projector **50** when the gap in the traffic on roadway **10** reaches the vehicle detector **D1**. During the time that gap detector **48** is determining whether this gap is great enough to permit merger into it of a vehicle from entrance ramp **16**, the gap is moving along roadway **10** toward merging area **20** at the same speed that traffic is moving along roadway **10**. This progress of the gap along roadway **10** is marked by the progression of the gap indication through shift register **200** at a rate dependent upon the speed of traffic on roadway **10**, as indicated by speed computer **30** and level monitor **32**. Thus, by the time that gap detector **48** generates signal **G1** on line **49**, the front edge of the gap has proceeded down roadway **10** to a "decision point" indicated in FIGURE 1 as point P. At that time, the gap indication is transferred from shift register **200** to shift register **202** within gap projector **50**. Shift register **200** must contain enough stages to store the entire gap indication for a gap of the maximum length required to generate signal **G1**. This gap length is determined by which indication **L1–L4** is applied from level monitor **58** to gap detector **48**, and the rate at which it passes through shift register **200** is determined by which indication **L1–L10** is applied from level monitor **32** to controlled multivibrator **208** via lines **33**.

As the gap continues down roadway **10** toward merging area **20**, the gap indication progresses through shift register **202**, and when the indication reaches the last shift register stage **202Z**, to transmit signal **G1'** on line **52**, the front edge of the gap has reached a "release point" on roadway **10**, indicated in FIGURE 1 at point R. Signal sequence timer and conroller **44** then generates the green or "go" indication on output line **266** to cause control signal **24** to release the waiting vehicle on entrance ramp **16**. This vehicle accelerates on entrance ramp **16**, and it must reach merging area **20** when the gap is at the merging area **20**. Thus, the release point R must be located so that the gap, moving at the same rate as traffic on roadway **10**, and the vehicle on entrance ramp **16**, accelerating from rest in front of control signal **24**, both require approximately the same amount of time to travel to merging area **20**.

The rate at which the gap proceeds down roadway **10** from release point R to merging area **20** varies with the speed of traffic on roadway **10**. However, since the vehicle on entrance ramp **16** must accelerate from in front of control signal **24** to merging area **20** while the gap is moving from release point R to merging area **20**, the length of time which passes between arrival of the gap at lease point R and arrival of the gap at merging area **20** is substantially constant. Thus, the distance from release point R to merging area **20** increases as the speed of traffic on roadway **10** increases. Accordingly, inputs **L1–L10** are applied as enabling inputs to the AND gates **206** in an inverse order. Signal **L10**, representing a high speed of traffic on roadway **10**, enables AND gate **206***a* which provides signal **G1'** on output line **52** when the gap is a substantial distance away from merging area **20**. Each subsequent input signal **L9–L1** enables an associated AND gate **206** which provides signal **G1'** at a later time, when the gap is closer to merging area **20**. Thus, the time available for a vehicle to accelerate on ramp **16** to meet the gap at merging area **20** is maintained substantially constant.

While FIGURE 4 depicts AND gates **206***a*, **206***b*, **206***i* and **206***j* associated with particular stages of shift register **202**, this is only a representative example. The particular stage with which each AND gate **206** is assoicated depends upon the characteristics of the entrance ramp at which the control system is utilized, and to provide increased flexibility, the AND gates **206** can be selectively connected to shift register **202** by means of patch cords or switching. Selector switches, for example, could be

calibrated in terms of percentage of total distance from D1 to nearly the merging area.

An alternative arrangement for providing a fixed acceleration time between the generation of signal G1' on line 52 and arrival of the gap at merging area 20 is to select the values of resistance placed in the timing circuitry of controlled multivibrator 208 by the signals L1–L10 so that the multivibrator repetition rate increases with increased speed on roadway 10 in a manner which shifts the gap indication through shift registers 200 and 202 at a rate to bring the indication to the output of stage 202Z at the appropriate release time. In such a case, output line 52 is tied only to the output of shift register stage 202Z.

Since shift register 200 and 202 simply delay signal G1–G1' and signal G2–G2' in accordance with the speed of traffic on roadway 10, a suitably adjusted time delay under the control of the traffic speed may be used to provide outputs G1' and G2' at suitable times after generation of signals G1 and G2. To accommodate a plurality of sequential gaps existing between detector D1 and release point R simultaneously, a number of time delay circuits can be arranged to be used in a manner similar to a telephone exchange line finder. Similarly, the gap could be placed into a computer-type memory device as a given real time clock value which could be arranged for look up at the particular time corresponding to the location of release point R as determined by the traffic speed on roadway 10.

Vehicle detector D1 must be far enough upstream from merging area 20 to insure that the decision point P is upstream of the release point R for the maximum traffic speed on roadway 10 and the minimum speed of vehicles through merging area 20. Thus, the distance which detector D1 is located upstream of merging area 20 is dependent upon the maximum speed at which traffic moves on roadway 10, the minimum speed of vehicles through merging area 20, the distance from control signal 24 to merging area 20, and the acceleration rate of vehicles on entrance ramp 16. This distance, thus, must be determined for each entrance ramp.

If one acceptable gap is ended by passage of a single vehicle past vehicle detector D1 and a second acceptable gap then follows, controller 44 might be providing a yellow or "clearance" indication to control signal 24 via line 268 at the time the second G1' signal is applied on line 66. Consequently, there will be no input applied to AND gate 246 from timer 270 at the time the G1' signal passes through OR gate 240 to the other input of AND gate 246. Timer 270 insures that the red indication on line 264 exists for at least a minimum time so that vehicles on ramp 16 will not be too closely spaced as they pass through merging area 20. By the time that timer 270 applies an enabling input to AND gate 246, the second gap may have terminated. In such a case, the G1' signal on line 66 through OR gate 240 to AND gate 246 will have ended. Consequently, the green indication is not initiated. This prevents the system from signalling to a car to proceed to merging area 20 too late to merge into the gap.

Timer 270 is reset when the input signal to it from line 264 ends. The reset circuitry of timer 270 includes apparatus such as a one-shot multivibrator which delays the resetting of the timer to insure that the timer output has reset flip-flop 254 before the timer 270 output ends.

If the driver of the vehicle waiting in front of indicator 24 on entrance ramp 16 hesitates instead of proceeding on the entrance ramp 16 once control signal 24 releases him to advance toward merging area 20, it is possible that the gap in the traffic on roadway 10 into which he is to merge will have passed merging area 20 before his vehicle gets to the merging area. Therefore, the green indication on line 266 from the set output of flip-flop 256 is applied to one input of AND gate 274. Since there is no signal on input line 70, INHIBITED-AND gate 291 is not blocked. The set output from flip-flop 290 is applied through INHIBITED-AND gate 291 to the other input of AND gate 274. Coincidence of these two inputs to AND gate 274 causes an output from the AND gate 274 which is applied to timer 276. Once this timer has timed out, a signal is applied from it through OR gate 259 to the first signal input of INHIBITED AND gate 261. This input to INHIBITED-AND gate 261 causes the same sequence as would a signal from vehicle detector D3. Thus, the control signal is cycled from its green indication through yellow and back to red, and the hesitating driver must wait for another gap to appear in the traffic on roadway 10.

If the gap in the traffic on roadway 10 is of a duration long enough to permit more than one car to merge into the traffic on roadway 10, then within gap detector 48 the voltage on capacitor 164 increases until triode 162 conducts, energizing relay 168 and causing output signal G2 on line 51. Signal G2 is transmitted to gap projector 50 in which it sets flip-flop 216. The set output of flip-flop 216 enables AND gate 218. When the output signal G1' is generated on line 52 and is applied to the second input of AND gate 218, output signal G2' is generated on line 54.

Signal G2' is supplied by line 54 to signal sequence timer and controller 44 in which it passes through OR gate 238 to inhibit INHIBITED-AND gate 261. Thus, if the green indication is being transmitted on output line 266 from flip-flop 256 when signal G2' reaches controller 44, controller 44 is inhibited from proceeding to the yellow and the red indications.

If at the time signal G2' reaches controller 44, the controller is not providing the green indication on its output line 266, then the controller continues its sequence until timer 270 has timed the minimum red duration, and an enabling input is applied by timer 270 to AND gate 246. The G1' signal on line 52 is present at all times that the G2' signal is present on line 54. Consequently, if a vehicle is within the detection zone of vehicle detector D4, and no vehicle is stopped within the detection zone of vehicle detector D2. INHIBITED-AND gate 53 applies a G1' signal on line 66 to cause controller 44 to step from the red indicator on line 264 to the green indication on line 266, as described above. However, the G2' signal on line 54 passes through OR gate 238 to the inhibit input of INHIBITED-AND gate 261. Therefore, the green indication continues for as long as the signal G2' is present, and vehicles on entrance ramp 16 are continuously released toward merging area 20.

When the gap ends and the end of the gap has been transmitted through all of the stages of shift register 202 within gap projector 50, signal G2' ends, resetting flip-flop 216 within gap projector 50. The negative pulse marking the termination of signal G2' passes through diode 257 to trigger one-shot 258. The output from one-shot 258 passes through OR gate 259 to INHIBITED-AND gate 261. Since the G2' signal is no longer present and the green indication on line 266 is present, INHIBITED-AND gate 261 provides a signal which resets flip-flop 256 and sets flip-flop 262. This terminates the green indication on output line 266 and initiates the yellow indication on output line 268.

After passing through OR gate 238, the G2' signal sets flip-flop 292 which enables AND gate 282 and inhibits INHIBITED-AND gate 284. Thus, the set output of flip-flop 262 passes through timer 278 which times a long duration yellow or "clearance" interval before applying a signal to the other input of AND gate 282. Coincidence of the two inputs to AND gate 282 results in a signal from gate 282 passing through OR gate 286 to trigger one-shot 287. The one-shot output resets flip-flops 262 and 292 and sets flip-flop 254. Thus, a long duration gap in the traffic on roadway 10 results in the signal G2' which permits the continuous release of vehicles until the end of the gap, at which time a long yellow

or "clearance" signal is provided before the control 24 returns to its red indication.

When the traffic on limited-access roadway 10 is light, the volume is low and the traffic travels at a relatively high speed. Therefore, level monitor 38 provides a signal to AND gate 40 to indicate that the volume of traffic passing vehicle detector D1 is low, and level monitor 34 provides a signal to AND gate 40 to indicate that the speed of vehicles passing vehicle detector D1 is high. Coincidence of these two signals at AND gate 40 causes the AND gate to provide a voltage on line 42 to signal sequence timer and controller 44 in which the voltage passes through OR gate 240. This signal through OR gate 240 causes controller 44 to cycle to its green output indication on line 266, just as did the signal G1' which passed through OR gate 240 on line 66. Similarly, this signal on line 42 passes through OR gate 238 to the inhibit input of INHIBITED-AND gate 261 so that the green or "go" indication from controller 44 continuously permits release of vehicles.

When the traffic volume increases or the traffic speed decreases so that there is no longer a coincidence of inputs at AND gate 40, the signal on line 42 is terminated. The resulting negative-going pulse passes through diode 257 to trigger ont-shot multivibrator 258. The output from one-shot 258 passes through OR gate 259 to INHIBITED-AND gate 261. Since there is no longer a signal on line 42, there is no input at the inhibit input of INHIBITED-AND gate 261. The green indication from line 266 is applied to INHIBITED-AND gate 261, and so the gate 261 provides a signal which resets flip-flop 256 and which sets flip-flop 262. The signal on line 42 passes through OR gate 238 to set flip-flop 292. The output of flip-flop 292 enables AND gate 282 and blocks INHIBITED-AND gate 284. Consequently, timer 278 times a long duration yellow or "clearance" interval before an output from AND gate 282 passes through OR gate 286 to trigger one-shot 287 which resets flip-flops 262 and 292 and sets flip-flop 254, returning the controller to its red indication.

If the traffic flow on limited-access roadway 10 is extremely heavy, then it is possible that long periods of time will pass without a gap being detected with a duration sufficient to permit a vehicle from entrance ramp 16 to merge into it. If a large number of vehicles from frontage road 18 want to enter limited-access roadway 10 by means of entrance ramp 16, then a line of waiting vehicles will form in front of control signal 24. If this line becomes long enough, it will reach turning area 22 adjacent the traveled portion of frontage road 18, and a vehicle will stop within the detection zone of detector D5. If vehicles continue to line up waiting to enter entrance ramp 16, they will form a line on frontage road 18, and as a result the traffic on the frontage road will be impeded.

To prevent interference with the traffic on frontage road 18, an input is applied to timer 68 when a vehicle is within the detection zone of vehicle detector D5. Should that input continue for a long period of time, as is the case when a vehicle stops within the detection zone of detector D5, timer 68 applies a signal to INHIBITED-AND gtae 62. If there is also a vehicle within the detection zone of detector D4, immediately in front of control signal 24, then detector D4 applies an input to INHIBITED-AND gate 62. If no vehicle is waiting within the detection zone of detector D2 in merging area 20, then no inhibit input is applied to INHIBITED-AND gate 62, and the gate provides a signal on line 70 to controller 44.

This signal on line 70 is applied to AND gate 250 within controller 44. Since the controller is indictaing red, the timer 270 is applying an output to the second input of AND gate 250. Gate 250 therefore applies a signal to the input of time delay circuit 252. When this circuit has timed out, a signal from it passes through OR gate 248 to reset flip-flop 254 and to set flip-flop 256. As a consequence, the red indication on output line 264 from controller 44 terminates, and the green indication on output line 266 is initiated. The vehicle at the front of the line waiting before control signal 24 is then released to proceed on entrance ramp 16 toward merging area 20. When this vehicle passes over detector D3, ground is applied on line 64 to the input of inverting amplifier 260 and so a signal passes through OR gate 259 and INHIBITED-AND gate 261 to reset flip-flop 256 and to set flip-flop 262. This terminates the green indication and initiates the yellow indilation.

The signal on line 70 passes through OR gate 288 to set flip-flop 290. The set output of flip-flop 290 is applied to a signal input of INHIBITED-AND gate 284. Since flip-flop 292 is reset, there is no signal applied to the inhibit input of INHIBITED-AND gate 284. The signal on output line 268 from flip-flop 262 is applied to timer 280 which times a short duration yellow or "clearance" interval and then applies an input to the second signal input of INHIBITED-AND gate 284.

Gate 284 generates a signal which passes through OR gate 286 to trigger one-shot 287 which resets flip-flops 262 and 290 and sets flip-flop 254, returning the controller to its red indication. If another vehicle is waiting within the detection zone of detector D5, timer 68 times out, and the cycle is repeated to release another vehicle. Thus, so long as the line of vehicles stretches along entrance ramp 16 to the detection zone of detector D5, controller 44 cycles through its red-green-yellow sequence at a rate determined by timer 68, timer 270, timer 280, and time delay circuit 252. The vehicles which reach merging area 20 during such a sequence shorten the line waiting on entrance ramp 16 to reduce the likelihood of that line interfering with traffic on frontage road 18. These vehicles which pass control signal 24 in such a situation can pause in merging area 20 until the driver detects a gap in the traffic on roadway 10 into which he can merge.

If a car is stopped within the detection zone of vehicle detector D2 in merging area 20, either because the driver of the vehicle did not enter a gap which was detected by vehicle detector D1 or because a continuing signal from vehicle detector D5 resulted in the cycling of controller 44, an input is applied from detector D2 to timer 60. If the vehicle waits within the detection zone of detector D2 for the length of time required for timer 60 to time out, the timer 60 applies inhibiting inputs to INHIBITED-AND gates 53 and 62. These inhibiting inputs prevent the generation of the green indication by controller 44 even though an acceptable gap is detected by vehicle detector D1 and even though vehicles might be waiting in turning area 22 within the detection zone of vehicle detector D5. As a consequence, control signal 24 is prevented from releasing a vehicle toward merging area 20 when that merging area is already occupied.

Variations in the logic within signal sequence timer and controller 44 can of course be made. For example, when the volume of traffic passing vehicle detector D1 is low and the speed is high, the signal applied on line 42 to controller 44 can be utilized to reset flip-flops 254, 256, and 262 so that control signal 24 provides no indication at all. Vehicles utilizing entrance ramp 16 will then proceed at the discretion of their drivers. If a particular entrance ramp location does not present a possible problem of interference with traffic on a frontage road, such as frontage road 18, then vehicle detector D5, timer 68, INHIBITED-AND gate 62, input line 70 to controller 44, AND gate 250, and time delay 252 can be omitted. Alternatively, in place of traffic speed and volume, other traffic flow parameters such as density or percentage occupancy can be utilized to control the signal on line 42.

With certain entrance ramps it might be found that the minimum gap duration required for a vehicle to merge onto the limited-access roadway can be judged better by

utilizing speed of vehicles on the limited-access roadway at a point immediately upstream of the merging area, rather than utilizing the speed of the vehicles passing through the detection zone of vehicle detector D2 within the merging area. In such a case, an additional vehicle detector, depicted in FIGURE 1 as vehicle detector D6, is provided to monitor the speed of traffic in the right-hand lane of the limited-access roadway as it nears the merging area, and the input to speed computer **56** is connected to this vehicle detector D6, rather than to vehicle detector D2. Alternatively, another traffic characteristic can be used in place of speed to determine the required gap length. For example, the density or volume of traffic on roadway **10** can be determined by connecting vehicle detector D6 to a density computer or to a volume computer, the output of which is tied to level monitor **58**. The required gap length is then varied in accordance with traffic density or traffic volume on roadway **10**. As another alternative, traffic density, volume and speed could be combined to control the required gap length.

If it is desired to permit only one vehicle at a time to proceed on entrance ramp **16** when a long duration gap exists in the traffic on roadway **10**, as indicated by signal G2', then line **54** is omitted. Then controller **44** will continuously cycle through its red-green-yellow sequence at a rate determined by timers **270**, **276** and **280**, as long as signal G1' exists on line **66**.

Gap detector **48**, depicted in FIGURE 3, can be modified by depleting relay **134**. In this case, relay contact **132***b* is coupled to the positive voltage source through resistor **134***g* and rheostat **134***h* and relay contact **132***e* is coupled to the positive voltage source through resistor **134***i* and rheostat **134***j*. The output line L4 is also omitted from relay contact **116***c* in level monitor **58**. Then, when the speed of vehicles passing through the detection zone of vehicle detector D2 is in the highest speed range, no signal is applied from level monitor **58** to gap detector **48**. Therefore, relays **128–132** are all de-energized, and charging paths for capacitors **144** and **164** are provided through resistors **134***g* and **134***i* and rheostats **134***h* and **134***j* and through all the normally-closed relay contacts. While the level monitor illustrated in FIGURE 2 and the gap detector illustrated in FIGURE 3 depict circuit values, these values are only representative of values which might be utilized in workable embodiments of these circuits and are not limitations.

Level monitor **32** and controlled multivibrator **208** within gap projector **50** generate output pulses with a repetition rate dependent upon the level of the output voltage from speed computer **30**. In place of level monitor **32** and controlled multivibrator **208**, a voltage controlled oscillator can be utilized.

At some entrance ramps, it might be desired to provide a minimum control system to signal for one car to merge onto the limited-access roadway each time a gap of sufficient length occurs in the traffic on the roadway. In such a minimum system, vehicle detector D5, timer **68**, gate **62**, and the associated circuitry within controller **44**, volume computer **36**, level monitors **34** and **38**, AND gate **40** and its associated circuitry within controller **44**, flip-flop **216**, AND gate **218**, and the associated circuitry within gap projector **50** can be eliminated. Such a minimum system will provide a green or "go" indication each time the signal G1' is generated to show that a gap has been detected with a duration long enough to allow a car from entrance ramp **16** to merge into the traffic on roadway **10**. A manual control can be provided to turn the system off when the traffic flow does not require its use.

As another alternative, vehicle detector D4 can be eliminated so that each time signal G1' on line **52** from gap projector **50** indicates that an acceptable gap has reached release point R, controller **44** causes control signal **24** to give a green or "go" indication which continues either until a vehicle passes through the detection zone of vehicle detector D3 or until time delay **276** times out to step controller **44** to its yellow or "clearance" indication. If desired, vehicle detector D3 can also be eliminated so that the duration of the green or "go" indication from control signal **24** is terminated only by operation of time delay **276**.

While preferred embodiments of particular components of the traffic control system have been described, these are illustrative examples only, and they are not intended as limitations. Other equivalent devices can be used in place of one or more of these components and still be within the present invention.

The invention has been discussed with reference to a limited-access roadway and an entrance ramp. It is, of course, obvious that it can be utilized to control traffic entering any heavily travelled main roadway from a comparatively lightly travelled side roadway. Thus, it can be utilized at the intersection of an arterial highway and merging side street or at a merging access road on a bridge or in a tunnel. In addition, while traffic in the right-hand lane of roadway **10** has been monitored by vehicle detector D1 to determine the presence of acceptable gaps, it would be possible to monitor instead the traffic in a different lane or in a combination of lanes on roadway **10**.

Level monitor **58** and gap detector **48** have been depicted as dividing the speed input information into discrete levels and varying the gap time duration required to generate signal G1 in discrete increments. Obviously a voltage divider network could be utilized to provide smooth variations instead of incremental variations.

If flip-flop **256** within signal sequence timer and controller **44** requires it, a one-shot multivibrator can be inserted into the line between the set output of flip-flop **256** and the input of INHIBITED-AND gate **261** to insure that the pulse which resets flip-flop **256** is of sufficient duration.

Another description of the volume computer suited for use as volume computer **36** is found in U.S. Patent No. 2,932,003 issued to John L. Barker, Apr. 5, 1960.

Thus, among others, the several objects of the invention, as specifically aforenoted, are achieved.

We claim:

1. Apparatus for controlling the entry of vehicles into traffic flow on a main roadway from a side roadway which terminates in a merging area with said main roadway, said apparatus used with vehicle detection means of the type which provide indications of vehicle presence and speed and used with signalling means which signals vehicles on said side roadway approaching said merging area to enter said main roadway traffic flow, said apparatus comprising in combination:

first electronic circuit means connected to said vehicle detection means for determining the occurrence of a gap of at least a pre-set duration in said main roadway traffic flow upstream of said merging area;

a second circuit means connected to said first electronic circuit means and connected to said signalling means for causing said signalling means to signal said approaching vehicle to advance to said merging area to allow said approaching vehicle to reach said merging area with substantial speed to merge into said gap when said gap is at said merging area.

2. Apparatus as claimed in claim **1** further comprising means responsive to at least one characteristic of traffic flow on said roadways for varying said pre-set duration.

3. Apparatus for controlling the entry of vehicles into traffic flow on a main roadway from a side roadway which terminates in a merging area with said main roadway, said apparatus used with vehicle detection means of the type which provide indications of vehicle presence and speed and used with signalling means which signals vehicles on said side roadway approaching said merging area to enter said main roadway traffic flow, said apparatus comprising in combination:

first electronic circuit means connected to said vehicle detection means for determining the occurrence of a gap of at least a pre-set duration in said main roadway traffic flow upstream of said merging area;

a second electronic circuit means connected to said first electronic circuit means and connected to said vehicle detection means for predicting a time when said detected gap is passing a release point on said main roadway, said release point being located so that advancement by said approaching vehicle toward said merging area from adjacent said signalling means on said side roadway at the time said detected gap is passing said release point permits said approaching vehicle to reach said merging area with substantial speed to merge into said detected gap when said detected gap is at said merging area;

third circuit means connected to said second electronic circuit means and connected to said signalling means for causing said signalling means to signal to said approaching vehicle to enter said main roadway traffic flow at said predicted point in time.

4. Apparatus as claimed in claim 3 further comprising means connected to said third circuit means and connected to said vehicle detection means for inhibiting said signalling means from signalling to said approaching vehicle to enter said main roadway traffic flow when another vehicle is stopped within said merging area.

5. Apparatus as claimed in claim 3 further comprising means for repeatedly causing said signalling means to signal a vehicle to enter said main roadway traffic flow when vehicles approaching said signalling means exist in a line in excess of a pre-set length.

6. Apparatus as claimed in claim 3 wherein said second electronic circuit means includes means for varying the location of said release point in accordance with a characteristic of traffic flow on said main roadway.

7. Apparatus as claimed in claim 3 in which said second electronic circuit means includes means for simultaneously predicting times when each of a plurality of detected gaps is passing said release point.

8. Apparatus as claimed in claim 3 further comprising means responsive to at least one characteristic of traffic flow on one of said roadways for varying said pre-set duration.

9. Apparatus as claimed in claim 8 wherein said responsive means varies said pre-set duration in accordance with speed on one of said roadways.

10. Apparatus as claimed in claim 8 wherein said responsive means includes a timing circuit having a time constant dependent upon said traffic flow characteristics.

11. Apparatus as claimed in claim 8 further comprising means for causing said signalling means to continuously signal to approaching vehicles to enter said main roadway traffic flow when said detected gap exceeds a second pre-set duration.

12. Apparatus as claimed in claim 3 in which said third circuit means is connected to said vehicle detection means and includes means to enable said signalling means to signal to said approaching vehicle to enter said main roadway traffic flow at said predicted point in time only if said approaching vehicle has reached a point on said side roadway immediately upstream of said signalling means.

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