

[54] **ELECTRONIC FUEL INJECTION SYSTEM**

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[58] Field of Search **123/32 EA, 119 R**

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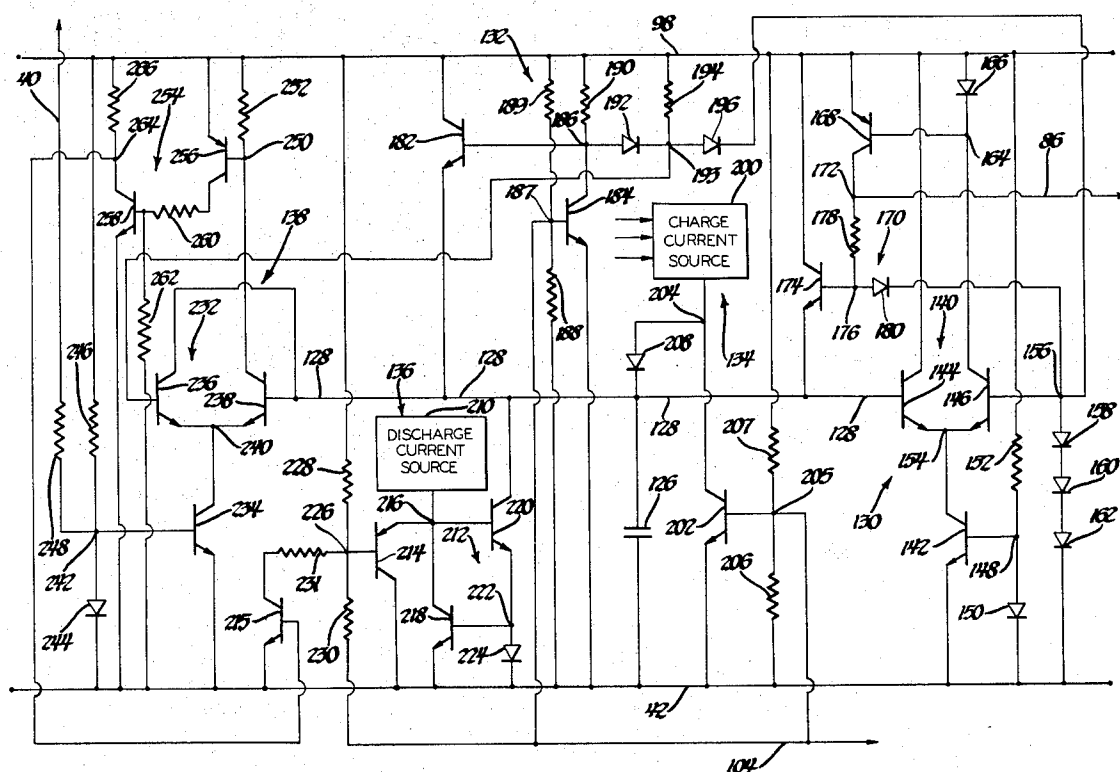
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[57] **ABSTRACT**

A control voltage is developed across a capacitor. In synchronization with the operation of an internal com-

bustion engine, the capacitor is charged with a charge current to increase the control voltage from an intermediate level to a peak level. In response to the arrival of the control voltage at the peak level, the capacitor is discharged with a first discharge current to decrease the control voltage from the peak level back to the intermediate level. In response to the arrival of the control voltage back at the intermediate level, the capacitor is further discharged with a second discharge current to decrease the control voltage from the intermediate level to a base level. The peak level of the control voltage is determined as a preselected function of a primary engine operating parameter such as intake air pressure. At least one of the charge current and the first discharge current of the capacitor is determined as a preselected function of a secondary engine operating parameter, such as engine temperature, which is multiplicatively related to the primary engine operating parameter. At least one of the second discharge current of the capacitor and the intermediate level and the base level of the control voltage is determined as a preselected function of a secondary engine operating parameter, such as battery supply voltage, which is additively related to the primary engine operating parameter.

3 Claims, 4 Drawing Figures



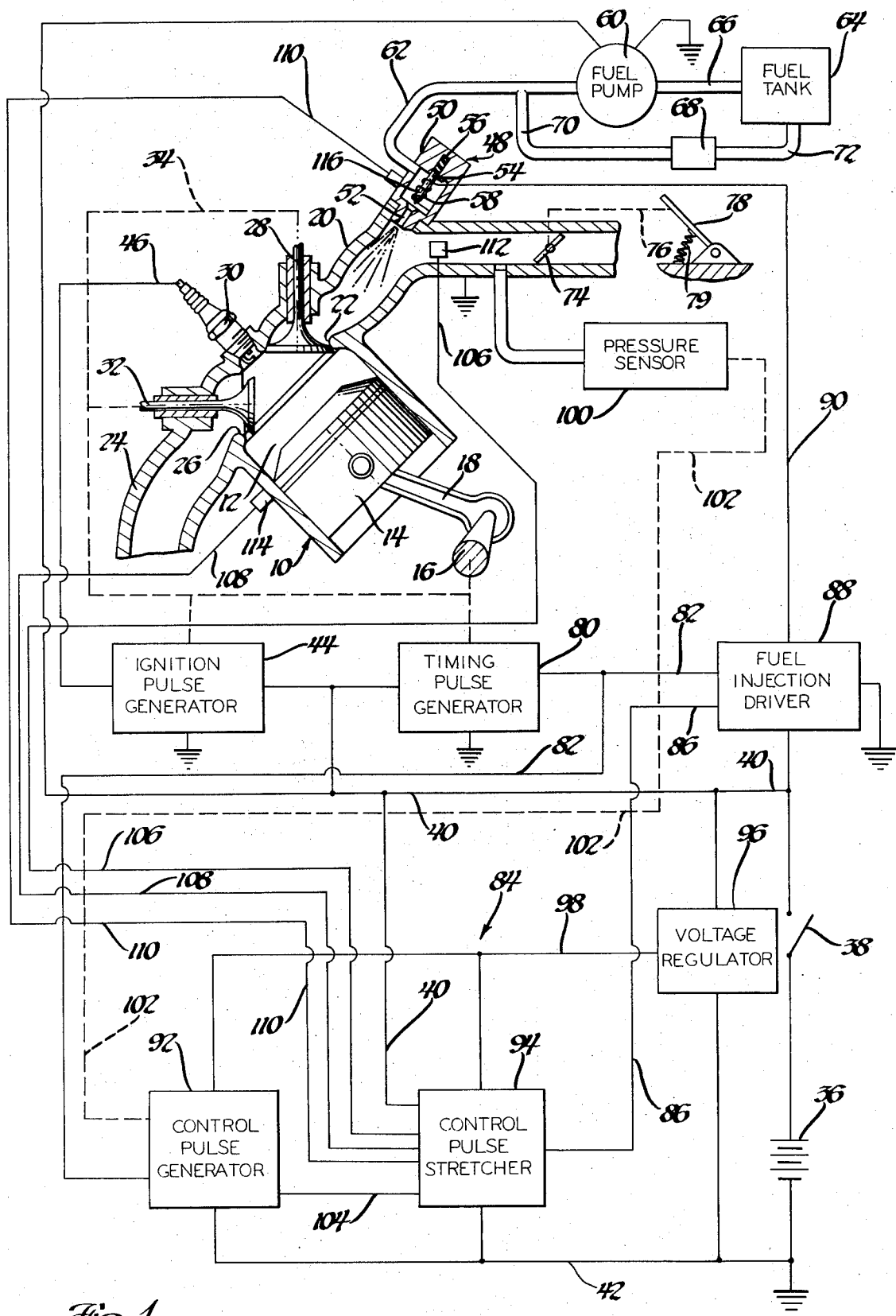
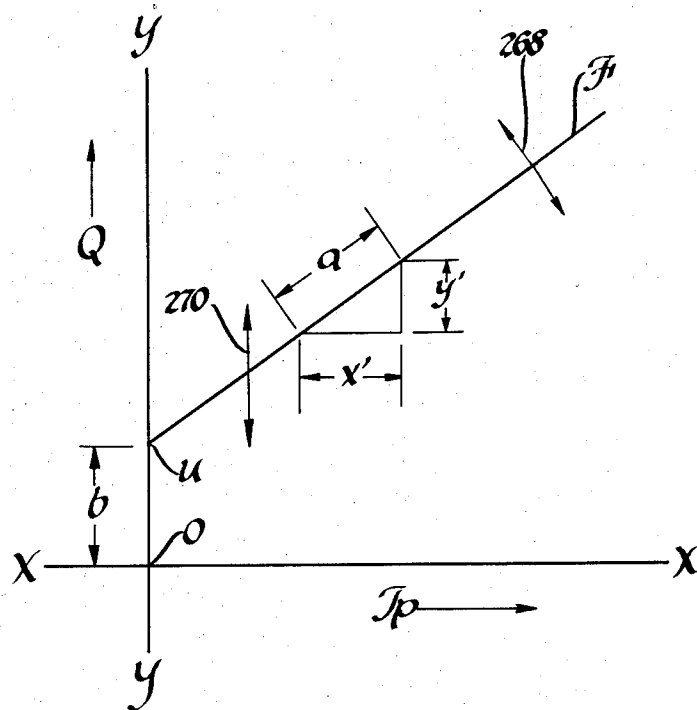
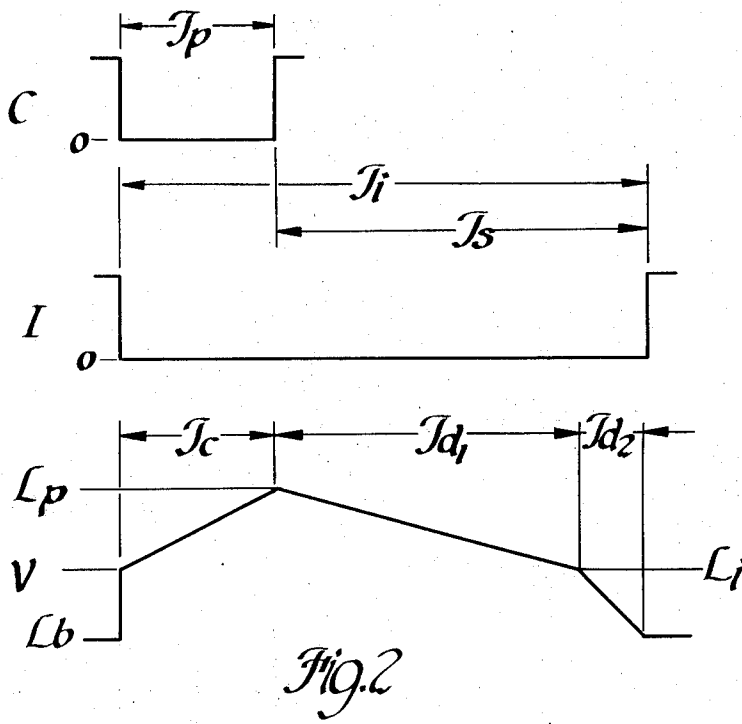


Fig. 1



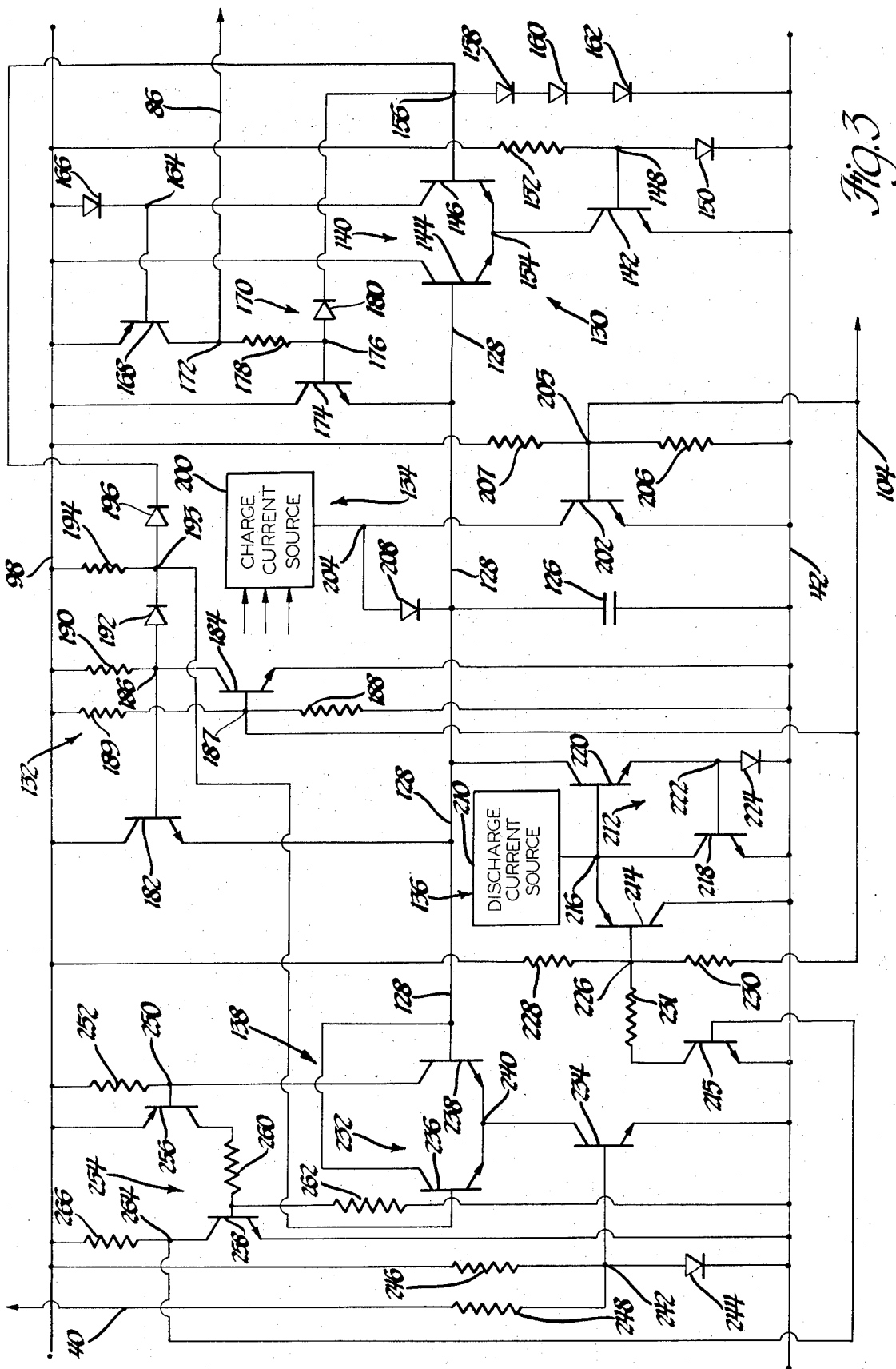


Fig. 3

ELECTRONIC FUEL INJECTION SYSTEM

This invention relates to a fuel supply system for an internal combustion engine. More particularly, the invention relates to an electronic fuel injection system.

According to the invention, a control voltage is developed across a capacitor having a capacitance C . The capacitor is alternately charged and discharged in synchronization with the operation of the engine. Specifically, the capacitor is charged with a charge current I_c to increase the control voltage from an intermediate level L_i to a peak level L_p over a charge time period. In response to the arrival of the control voltage at the peak level L_p , the capacitor is discharged with a first discharge current I_{d1} to decrease the control voltage from the peak level L_p back to the intermediate level L_i . In response to the arrival of the control voltage back at the intermediate level L_i , the capacitor is further discharged with a second discharge current I_{d2} to decrease the control voltage from the intermediate level L_i to a base level L_b .

The peak level L_p of the control voltage is determined as a preselected function of a primary engine operating parameter such as intake air pressure. Preferably, the charge time period of the capacitor is defined by a primary time period T_p which is regulated in response to the primary engine operating parameter thereby to indirectly determine the peak level L_p of the control voltage.

In addition, at least one of the charge current I_c and the first discharge current I_{d1} of the capacitor is determined as a preselected function of a secondary engine operating parameter, such as engine temperature, which is multiplicatively related to the primary engine operating parameter. Further, at least one of the second discharge current I_{d2} of the capacitor and the intermediate level L_i and the base level L_b of the control voltage is determined as a preselected function of a secondary engine operating parameter, such as battery supply voltage, which is additively related to the primary engine operating parameter.

Fuel is applied to the engine in an amount defined by the time interval established between the initial departure of the control voltage from the intermediate level L_i and the ultimate arrival of the control voltage at the base level L_b . Consequently, the total quantity of fuel Q delivered to the engine may be expressed by the following equation:

$$Q \neq T_p (I_c/I_{d1}) + (L_i - L_b) C/I_{d2}.$$

In relation to the primary engine operating parameter, the fuel quantity Q is defined by a linear fuel control curve characterized by a slope and an offset. The slope of the fuel control curve is defined by the preselected function of the secondary engine operating parameter which is multiplicatively related to the primary engine operating parameter. The offset of the fuel control curve is defined by the preselected function of the secondary engine operating parameter which is additively related to the primary engine operating parameter.

These and other aspects of the invention may be best understood by reference to the following detailed description of a preferred embodiment when considered in conjunction with the accompanying drawings. As used in equations appearing in both the specification

and the claims, the symbol " $=$ " means "is equal to" while the symbol " $\neq$ " means "is proportional to."

In the drawings:

FIG. 1 is a block diagram of an electronic fuel injection system incorporating the principles of the invention.

FIG. 2 is a graphic illustration of several waveforms useful in explaining the operation of the electronic fuel injection system shown in FIG. 1.

FIG. 3 is a schematic diagram of a portion of the electronic fuel injection system shown in FIG. 1.

FIG. 4 is a graphic illustration of a fuel control curve useful in explaining the operation of the electronic fuel injection system shown in FIG. 1.

Referring to FIG. 1, an internal combustion engine 10 for an automotive vehicle includes a combustion chamber or cylinder 12. A piston 14 is mounted for reciprocation within the cylinder 12. A crankshaft 16 is supported for rotation within the engine 10. A connecting rod 18 is pivotally connected between the piston 14 and the crankshaft 16 for rotating the crankshaft within the engine 10 when the piston 14 is reciprocated within the cylinder 12. Conventionally, a fluid coolant is circulated over the exterior wall of the cylinder 12 by a coolant system (not shown) to dissipate excessive heat generated within the combustion chamber 12.

An intake manifold 20 is connected with the cylinder 12 through an intake port 22. An exhaust manifold 24 is connected with the cylinder 12 through an exhaust port 26. An intake valve 28 is slidably mounted within the top of the cylinder 12 in cooperation with the intake port 22 for regulating the entry of combustion ingredients into the cylinder 12 from the intake manifold 20. A spark plug 30 is mounted in the top of the cylinder 12 for igniting the combustion ingredients within the cylinder 12 when the spark plug 30 is energized. An exhaust valve 32 is slidably mounted in the top of the cylinder 12 in cooperation with the exhaust port 26 for regulating the exit of combustion products from the cylinder 12 into the exhaust manifold 24. The intake valve 28 and the exhaust valve 32 are driven through a suitable linkage 34 which conventionally includes rocker arms, lifters, and a camshaft.

An electrical power source is provided by the vehicle battery 36. An ignition switch 38 connects the battery 36 between a power line 40 and a ground line 42. When the ignition switch 38 is closed, the battery 36 applies a supply voltage to the power line 40. A conventional ignition pulse generator 44 is electrically connected to the power line 40 and is mechanically connected with the crankshaft 16 of the engine 10. Further, the ignition pulse generator 44 is connected through a spark cable 46 to the spark plug 30. In the usual manner, the ignition pulse generator 44 energizes the spark plug 30 in synchronization with the rotation of the crankshaft 16 of the engine 10. Hence, the ignition pulse generator 44 combines with the ignition switch 38 and the spark plug 30 to form an ignition system.

A fuel injector 48 includes a housing 50 having a fixed metering orifice 52. A plunger 54 is supported within the housing 50 for reciprocation between a fully opened position and a fully closed position. In the fully opened position, the forward end of the plunger 54 is opened away from the orifice 52. In the fully closed position, the forward end of the plunger 54 is closed against the orifice 52. A bias spring 56 is seated between the rearward end of the plunger 54 and the hous-

ing 50 for normally maintaining the plunger 54 in the fully closed position. A solenoid or winding 58 is electromagnetically coupled with plunger 54 for retracting the plunger 54 to the fully opened position against the action of the bias spring 56 when the winding 58 is energized. The bias spring 56 drives the plunger 54 to the fully closed position when the winding 58 is deenergized. The fuel injector 48 is mounted on the intake manifold 20 of the engine 10 for injecting fuel into the intake manifold 20 at a constant flow rate through the metering orifice 52 when the plunger 54 is in the fully opened position. Notwithstanding the illustrated structure, it is to be noted that the fuel injector 48 may be provided by any suitable voltage responsive valve.

A fuel pump 60 is connected to the fuel injector 48 by a conduit 62 and to the vehicle fuel tank 64 by a conduit 66 for pumping fuel from the fuel tank 64 to the fuel injector 48. Preferably, the fuel pump 60 is connected to the power line 40 to be electrically driven from the vehicle battery 36. Alternately, the fuel pump 60 could be connected to the crankshaft 16 to be mechanically driven from the engine 10. A pressure regulator 68 is connected to the conduit 62 by a conduit 70 and is connected to the fuel tank 64 by a conduit 72 for defining the pressure of the fuel applied to the fuel injector 48. Thus, the fuel injector 48 combines with the fuel tank 64, the fuel pump 60 and the pressure regulator 68 to form a fuel supply system.

A throttle valve 74 is rotatably mounted within the intake manifold 20 for regulating the flow of air into the intake manifold 20 from an air supply system (not shown) in accordance with the position of the throttle valve 74. The throttle valve 74 is connected through a suitable linkage 76 with the vehicle accelerator pedal 78. The accelerator pedal 78 is pivotably mounted on a reference surface for movement against the action of a compression spring 79 seated between the accelerator pedal 78 and the reference surface. As the accelerator pedal 78 is depressed, the throttle valve 74 is moved to a more opened position to increase the flow of air into the intake manifold 20. Conversely, as the accelerator pedal 78 is released, the throttle valve 74 is moved to a less opened position to decrease the flow of air into the intake manifold 20.

In operation, fuel and air are combined within the intake manifold 20 to form an air/fuel mixture. The fuel is injected into the intake manifold 20 at a constant flow rate by the fuel injector 48 in response to energization. The precise amount of fuel deposited within the intake manifold 20 is regulated by an electronic fuel injector control system which will be described later. The air enters the intake manifold 20 from the air supply system (not shown) which conventionally includes an air filter. The precise amount of air admitted into the intake manifold 20 is determined by the position of the throttle valve 74. As previously described, the position of the accelerator pedal 78 controls the position of the throttle valve 74.

As the piston 14 initially moves downward within the cylinder 12 on the intake stroke, the intake valve 28 is opened away from the intake port 22 and the exhaust valve 32 is closed against the exhaust port 26. Accordingly, combustion ingredients in the form of the air/fuel mixture within the intake manifold 20 are drawn by negative pressure through the intake port 22 into the cylinder 12. As the piston 14 subsequently moves upward within the cylinder 12 on the compression stroke,

the intake valve 28 is closed against the intake port 22 so that the air/fuel mixture is compressed between the top of the piston 14 and the top of the cylinder 12. When the piston 14 reaches the end of its upward travel on the compression stroke, the spark plug 30 is energized by the ignition circuit 44 to ignite the air/fuel mixture. The ignition of the air/fuel mixture starts a combustion reaction which drives the piston 14 downward within the cylinder 12 on the power stroke. As the piston 14 again moves upward within the cylinder 12 on the exhaust stroke, the exhaust valve 32 is opened away from the exhaust port 26. As a result, the combustion products in the form of various exhaust gases are pushed by positive pressure out of the cylinder 12 through the exhaust port 26 into the exhaust manifold 24. The exhaust gases pass out of the exhaust manifold 24 into the exhaust system (not shown) which conventionally includes a muffler and an exhaust pipe.

Although the structure and operation of only a single combustion chamber or cylinder 12 has been described, it will be readily appreciated that the illustrated internal combustion engine 10 may include additional cylinders 12 as desired. Similarly, additional fuel injectors 48 may be provided as required. However, as long as the fuel injectors 48 are mounted on the intake manifold 20, the number of additional fuel injectors 48 need not necessarily bear any fixed relation to the number of additional cylinders 12. Alternately, the fuel injector 48 may be directly mounted on the cylinder 12 so as to inject fuel directly into the cylinder 12. In such instance, the number of additional fuel injectors 48 would necessarily equal the number of additional cylinders 12.

A timing pulse generator 80 is connected with the crankshaft 16 for developing rectangular timing pulses having a frequency which is proportional to and synchronized with the rotating speed of the crankshaft 16. The rectangular timing pulses produced by the timing pulse generator 80 are applied to a timing pulse line 82. Preferably, the timing pulse generator 80 is provided by an inductive speed transducer coupled with a bistable switch.

An injection pulse generator 84 is coupled with the engine 10 for developing rectangular injection pulses having a length determined as a function of several different engine operating parameters. The injection pulses produced by the injection pulse generator 84 are synchronized with the timing pulses produced by the timing pulse generator 80. The injection pulses are applied by the injection pulse generator 84 to an injection pulse line 86. The injection pulse generator 84 will be more fully described later.

A fuel injector driver 88 is connected with the timing pulse line 82 and with the injection pulse line 86. Further, the fuel injector driver is connected through an injection drive line 90 to the fuel injector 48 and is connected to the vehicle battery 36 through the power line 40 and the ignition switch 38. The fuel injector driver 88 is responsive to the occurrence of the timing pulses produced by the timing pulse generator 80 to energize the fuel injector 48. The time period for which the fuel injector 48 is energized by the fuel injector driver 88 is defined by the length or duration of the injection pulses produced by the injection pulse generator 84. In other words, the fuel injector driver 88 is responsive to the coincidence of a timing pulse and an injection pulse to

energize the fuel injector 48 for the duration of the injection pulse.

The fuel injector driver 88 may be virtually any logic switch or amplifier capable of executing the desired coincident pulse operation. However, where additional fuel injectors 48 are provided, it may be necessary that the fuel injector driver 88 also select which one or ones of the fuel injectors 48 are to be energized in response to each respective timing pulse. As an example, the fuel injectors 48 may be divided into separate groups which are successively energized in response to succeeding ones of the timing pulses. Conversely, the timing pulses may be applied to a logic network which selects the fuel injectors 48 for individual energization.

The injection pulse generator 84 comprises a control pulse generator 92 and a control pulse stretcher 94. A voltage regulator 96 is connected between the unregulated power line 40 and the ground line 42 for providing a regulated supply voltage for the injection pulse generator 84 on a regulated power line 98. The control pulse generator 92 and the control pulse stretcher 94 are each connected between the regulated power line 98 and the ground line 42. The voltage regulator 96 may be provided by virtually any suitable regulating apparatus, such as a Zener diode.

Referring to FIGS. 1 and 2, the control pulse generator 92 repetitively produces a control pulse C which is initiated in synchronization with the operation of the engine 10 and which is terminated at the expiration of a primary time period T_p determined as a preselected function of a primary engine operating parameter. The control pulse stretcher 94 repetitively produces an injection pulse I which is initiated in response to the initiation of the control pulse C and which is terminated at the expiration of an injection time period T_i . More particularly, the injection pulse I is terminated at the expiration of a secondary time period T_s which is initiated in response to the termination of the control pulse C and which is determined as a function of the primary time period T_p . Further, the secondary time period T_s is determined as a preselected function of a secondary engine operating parameter which is multiplicatively related to the primary engine operating parameter and is also determined as a preselected function of a secondary engine operating parameter which is additively related to the primary engine operating parameter.

The control pulse generator 92 is connected to the timing pulse generator 80 through the timing pulse line 82 and is connected to a pressure sensor 100 through a suitable linkage 102. The pressure sensor 100 communicates with the intake manifold 20 of the engine 10 downstream from the throttle 74 for monitoring the pressure of the air within the intake manifold 20. The control pulses C produced by the control pulse generator 92 are applied to a control pulse line 104. The control pulses C are each initiated in response to the initiation of a timing pulse as received from the timing pulse generator 80. Further, the control pulses C each have a length or duration T_p defined as a preselected function of the air pressure within the intake manifold 20 as measured by the pressure sensor 100.

The principal function of the illustrated electronic fuel injection system is to regulate the amount of fuel delivered to the engine 10 in response to the amount of air delivered to the engine 10 thereby to maintain a predetermined air/fuel ratio. The pressure of the air within the intake manifold 20 is directly related to the

amount of air delivered to the engine 10 as regulated by the throttle 74. The amount of fuel delivered to the engine 10 is directly related to the length T_i of the injection pulses I, which in turn is directly related to the length T_p of the control pulses C. Accordingly, the length T_p of the control pulses C is defined by the control pulse generator 92 as a preselected direct function of the air pressure within the intake manifold 30 as measured by the pressure sensor 100. Hence, as the intake air pressure increases, the primary time period T_p increases to increase the injection time period T_i . Conversely, as the intake air pressure decreases, the primary time period T_p decreases to decrease the injection time period T_i . Preferably, the duration T_p of the control pulses C is defined as a linear or straight-line function of the air pressure within the intake manifold 20. However, it is to be understood that the primary time period T_p may be virtually any desired function of the intake air pressure.

The control pulse generator 92 may be provided by a switching circuit including a resistance-inductance timing network for defining the duration T_p of the control pulses C in accordance with the L/R time constant of the timing network. The inductance of the timing network may be mechanically varied by the pressure sensor 100 in response to changes in the pressure of the air within the intake manifold 20 thereby to define the length T_p of the control pulses C as a direct function of the intake air pressure. A more detailed description of one embodiment of the control pulse generator 92 may be obtained by reference to U.S. Pat. No. 3,623,459.

The control pulse stretcher 94 is connected to the control pulse generator 92 through the control pulse line 104 and is connected to the fuel injector driver 88 through the injection pulse line 86. In addition, the control pulse stretcher 94 is connected to the vehicle battery 36 through the unregulated power line 40. Further, the control pulse stretcher 94 is connected to a plurality of temperature sensor lines 106, 108 and 110. The first sensor line 106 is connected to an intake air temperature sensor provided by a thermistor 112 mounted within the intake manifold 20 of the engine 10 downstream from the throttle 74 for monitoring the temperature of the intake air. The second sensor line 108 is connected to an engine coolant temperature sensor provided by a thermistor 114 immersed within the cooling fluid surrounding the outer surface of the combustion chamber 12 for monitoring the general temperature of the engine 10 as manifested by the temperature of the engine coolant. The third sensor line 110 is connected to an injected fuel temperature sensor provided by a thermistor 116 and mounted to the fuel injector 48 for monitoring the temperature of the injected fuel.

The injection pulses I produced by the control pulse stretcher 94 are applied to the injection pulse line 86. The injection pulses I are each initiated in response to the initiation of a control pulse C as received from the control pulse generator 92. As previously described, the injection pulses I each have a length or duration T_i defined by the summation of the primary time period T_p and the secondary time period T_s . The secondary time period T_s is defined as a direct function of the primary time period T_p . In addition, the secondary time period T_s is defined as a preselected function of the supply voltage of the vehicle battery 36 as received via the unregulated power line 40. Moreover, the second-

primary time period T_s is defined as a preselected function of a temperature of the engine 10 as represented by the temperature of the intake air sensed by the thermistor 112, the temperature of the engine coolant sensed by the thermistor 114, and the temperature of the injected fuel sensed by the thermistor 116.

As before discussed, the fuel injector 48 includes a plunger 54 which is electromagnetically coupled with a winding 58. The winding 58 is energized for the duration T_i of the injection pulses I. Due to the inherent inductive properties of the plunger 54 and the winding 58, the plunger 54 arrives at a fully opened position some "pull-in" time interval after energization of the winding 58 in response to the initiation of an injection pulse I. Similarly, the plunger 54 arrives at a fully closed position some "drop-out" time interval after de-energization of the winding 58 in response to the termination of an injection pulse I. Both the "pull-in" time interval and the "drop-out" time interval are dependent upon the supply voltage of the vehicle battery 36 in such a manner that, assuming an injection pulse I of constant length T_i , the amount of fuel applied to the engine 10 is directly related to the magnitude of the battery supply voltage. The length T_i of the injection pulses I is directly related to the secondary time period T_s . Accordingly, the secondary time period T_s is defined by the control pulse stretcher 94 as a preselected inverse function of a supply voltage of the vehicle battery 36. Thus, as the battery voltage increases, the secondary time period T_s decreases to decrease the injection time period T_i . Conversely, as the battery voltage decreases, the secondary time period T_s increases to increase the injection time period T_i .

Assuming that a constant mass of air is delivered to the engine 10, the air pressure within the intake manifold 20 is directly related to the temperature of the intake air. In addition, when the engine 10 is relatively cold, the quantity of fuel which is condensed upon the surfaces of the intake manifold 20, the intake valve 22, etc. is inversely related to the temperature of these engine parts as manifested by the temperature of the engine coolant. Further, when the engine is very hot, the quantity of fuel which is vaporized within the intake manifold 20 is directly related to the temperature of the injected fuel, especially the fuel temperature at the nozzle of the fuel injector 48. Therefore, to accurately maintain a predetermined air/fuel ratio, the amount of fuel injected into the intake manifold 20 must be compensated for the effects of temperature upon intake air pressure, fuel condensation, and fuel vaporization.

The amount of fuel applied to the engine 10 is directly related to the length T_i of the injection pulses I, which in turn is directly related to the secondary time period T_s . Accordingly, the secondary time period T_s is defined by the control pulse stretcher 94 as a preselected inverse function of the intake air temperature, as a preselected inverse function of the engine coolant temperature, and as a preselected direct function of the injected fuel temperature. Preferably, the temperature of the engine coolant is effective to lengthen the injection time period T_i only when such temperature is below a value at which appreciable amounts of fuel are condensed, while the temperature of the injected fuel is effective to lengthen the injection time period T_i only when such temperature is above a value at which appreciable amounts of fuel are vaporized.

The structure and operation of one embodiment of the control pulse stretcher 94 is illustrated in FIGS. 2 and 3. A control capacitor 126 having a capacitance C is connected between a control line 128 and the ground line 42. A control voltage V is developed across the capacitor 126 on the line 128. Further, the control pulse stretcher 94 includes a switching circuit 130, a voltage booster 132, a charge circuit 134, a first discharge circuit 136 and a second discharge circuit 138.

The switching circuit 130 includes a differential switch 140 having a sink transistor 142 and a pair of switching transistors 144 and 146 all of the NPN junction type. The base electrode of the transistor 142 is connected directly to a junction 148. A biasing diode 150 is connected between the junction 148 and the ground line 42. A biasing resistor 152 is connected between the junction 148 and the regulated power line 98. The emitter electrode of the transistor 142 is connected directly to the ground line 42. The collector electrode of the transistor 142 is connected directly to a junction 154 located between the emitter electrodes of the transistors 144 and 146. The base electrode of the transistor 144 is connected directly to the control line 128. The collector electrode of the transistor 144 is connected directly to the regulated power line 98. The base electrode of the transistor 146 is connected directly to a junction 156. A string of reference diodes 158, 160 and 162 is connected in series between the junction 156 and the ground line 42. The collector electrode of the transistor 146 is connected directly to a junction 164. A biasing diode 166 is connected between the junction 164 and the regulated power line 98.

In addition, the switching circuit 130 includes a buffer transistor 168 of the PNP junction type and a clamping network 170. The base electrode of the transistor 168 is connected directly to the junction 164. The emitter electrode of the transistor 168 is connected directly to the regulated power line 98. The collector electrode of the transistor 168 is connected directly to the injection pulse line 86 at a junction 172. The clamping network 170 includes a clamping transistor 174 of the NPN junction type. The base electrode of the transistor 174 is connected directly to a junction 176. The emitter electrode of the transistor 174 is connected directly to the capacitor 126 via the control line 128. The collector electrode of the transistor 174 is connected directly to the regulated power line 98. A biasing resistor 178 is connected between the junction 172 and the junction 176. A clamping diode 180 is connected between the junction 176 and the junction 156.

In the differential switch 140, the sink transistor 142 is rendered conductive in a constant current mode through the biasing action of the diode 150 and the resistor 152. Accordingly, the transistor 142 provides a constant current sink at the junction 154 for the switching transistors 144 and 146. As a whole, the differential switch 140 is operable between a first state and a second state. When the potential on the line 128 equals the potential at the junction 156, the differential switch 140 shifts to the first state. In the first state, the transistors 144 and 146 are rendered equally conductive in a half-switched or partially conductive condition. When the potential on the line 128 exceeds the potential at the junction 156, the differential switch 140 shifts to the second state. In the second state, the transistor 144

is rendered fully conductive while the transistor 146 is rendered fully nonconductive. The potential on the line 128 is provided by the control voltage V as developed across the capacitor 126. The potential at the junction 156 is provided by a base voltage level L_b as developed across the reference diodes 158, 160 and 162. Specifically, the magnitude of the base voltage level L_b is defined by the summation of the characteristic anode-cathode junction voltage drops of the diodes 158, 160 and 162.

Normally, the differential switch 140 is maintained in the first state in which the switching transistors 144 and 146 are each in a partially conductive condition. With the transistor 146 turned on, the buffer transistor 168 is rendered fully conductive through the biasing action of the diode 166. With the transistor 168 turned on, both the clamping transistor 174 and the clamping diode 180 are rendered conductive through the biasing action of the resistor 178. With the diode 180 forward biased, the potential at the junction 176 is defined above the base voltage level L_b at the junction 156 by an amount equal to the characteristic anode-cathode junction voltage drop of the diode 180. With the transistor 174 turned on in an emitter-follower mode, the amplitude of the control voltage V on the line 128 is defined below the potential at the junction 176 by an amount equal to the characteristic base-emitter junction voltage drop of the transistor 174.

Ordinarily, the characteristic anode-cathode junction voltage drop of the diode 180 is substantially identical to the characteristic base-emitter junction voltage drop of the transistor 174. This is especially true where both the diode 180 and the transistor 174 are simultaneously fabricated through the application of integrated circuit processing techniques. Since the characteristic base-emitter junction voltage drop of the transistor 174 is equal to the characteristic anode-cathode junction voltage drop of the diode 180, the amplitude of the control voltage V on the line 128 is equal to the base voltage level L_b at the junction 156. In other words, the potential on the line 128 is pegged through the clamping network 170 to the potential at the junction 156. Therefore, the differential switch 140 is maintained in the first state.

When the amplitude of the control voltage V on the line 128 exceeds the base voltage level L_b at the junction 156, the differential switch 140 shifts to the second state in which the transistor 144 is rendered fully nonconductive and the transistor 146 is rendered fully nonconductive. With the transistor 146 turned off, the buffer transistor 168 is likewise rendered fully nonconductive through the biasing action of the diode 166. As the transistor 168 turns off, an injection pulse I is initiated on the injection pulse line 86 at the junction 172. Further, with the transistor 168 turned off, the clamping transistor 174 and the clamping diode 180 are both rendered fully nonconductive through the biasing action of the transistor 168 and the resistor 178. With the transistor 174 and the diode 180 turned off, the potential on the line 128 is completely unclamped from the potential at the junction 156. A more detailed description of switching circuit 130 may be obtained by reference to U.S. Pat. application Ser. No. 201,472.

The voltage booster 132 includes a boosting transistor 182 and a control transistor 184. The emitter electrode of the transistor 182 is connected directly to the line 128. The collector electrode of the transistor 182

is connected directly to the regulated power line 98. The base electrode of the transistor 182 is connected directly to the collector electrode of the transistor 184 at a junction 186. The emitter electrode of the transistor 184 is connected directly to the ground line 42. The base electrode of the transistor 184 is connected directly to the control pulse line 104 at a junction 187. A biasing resistor 188 is connected between the junction 187 and the ground line 42. A biasing resistor 189 is connected between the junction 187 and the regulated power line 98. A biasing resistor 190 is connected between the junction 186 and the regulated power line 98. A reference diode 192 is connected between the junction 186 and a junction 193. A biasing resistor 194 is connected between the junction 193 and the regulated power line 98. A reference diode 196 is connected between the junction 193 and the junction 156 in the switching circuit 130.

The control transistor 184 is rendered fully conductive through the biasing action of the resistors 188 and 189 in response to the absence of a control pulse C on the control pulse line 104. With the transistor 184 turned on, the junction 186 is effectively connected to the ground line 42 through the transistor 184. Actually, the potential at the junction 186 is maintained above the potential on the ground line 42 by an amount equal to the saturation voltage drop of the transistor 184. With the junction 186 effectively connected to the ground line 42, both the boosting transistor 182 and the reference diode 192 are rendered fully nonconductive through the biasing action of the transistor 184. With the transistor 182 turned off, it exerts no effect on the control voltage V on the line 128. The resistor 194 provides a bias current for the diodes 196, 158, 160 and 162.

When a control pulse C is initiated on the control pulse line 104, the control transistor 184 is rendered fully nonconductive. With the transistor 184 turned off, the junction 186 is effectively disconnected from the ground line 42. As a result, both the boosting transistor 182 and the reference diode 192 are rendered conductive through the biasing action of the resistor 190. As the transistor 182 turns on in an emitter-follower mode, it rapidly charges the capacitor 126 to substantially instantaneously increase the amplitude of the control voltage V from the base voltage level L_b to an intermediate voltage level L_i . The intermediate voltage level L_i is equal to the potential defined at the junction 186 less the characteristic base-emitter junction voltage drop of the transistor 182. The potential at the junction 186 is equal to the potential at the junction 156 plus the summation of the characteristic anode-cathode junction voltage drops of the diodes 192 and 196.

Again, assuming that the base-emitter junction voltage drop of the transistor 182 is substantially identical to the anode-cathode junction voltage drops of the reference diodes 192 and 196, the intermediate voltage level L_i defined on the line 128 is also developed at the junction 193. In turn, the intermediate voltage level L_i defined at the junction 193 is greater than the base voltage level L_b defined at the junction 156 by an amount equal to the characteristic anode-cathode junction voltage drop of the diode 196. Thus, the voltage booster 132 effectively shoves the amplitude of the control voltage V from the base voltage level L_b to the intermediate voltage level L_i in response to the initia-

tion of a control pulse C. Consequently, the differential switch 140 shifts to the second state.

The charge circuit 134 includes a charge current source 200 and a control transistor 202 of the NPN junction type. The current source 200 is connected directly to a junction 204. The collector electrode of the transistor 202 is also connected directly to the junction 204. The emitter electrode of the transistor 202 is connected directly to the ground line 42. The base electrode of the transistor 202 is connected directly to the control pulse line 104 at a junction 205. A biasing resistor 206 is connected between the junction 205 and the ground line 42. A biasing resistor 207 is connected between the junction 205 and the regulated power line 98. A control diode 208 is connected between the junction 204 and the line 128.

The charge current source 200 applies a constant charge current I_c to the junction 204. The transistor 202 is rendered fully conductive through the biasing action of the resistors 206 and 207 in response to the absence of a control pulse C on the control pulse line 104. With the transistor 202 turned on, the charge current I_c is effectively shunted through the transistor 202 to the ground line 42. When a control pulse C is initiated on the control pulse line 104, the transistor 202 is rendered fully nonconductive. With the transistor 202 turned off, the control diode 208 applies the charge current I_c to the line 128 to charge the capacitor 126. Under the influence of the constant charge current I_c , the amplitude of the control voltage V linearly increases from the intermediate voltage level L_i to a peak voltage level L_p over a charge time period T_c . The peak voltage level L_p of the control voltage V is established at the instant when the transistor 202 again turns on in response to the termination of a control pulse C on the control pulse line 104.

The first discharge circuit 136 includes a discharge current source 210, a discharge current sink 212 and a pair of control transistors 214 and 215. The current source 210 is connected directly to a junction 216. The discharge current sink 212 includes a pair of discharge transistors 218 and 220 of the NPN junction type. The collector electrode of the transistor 218 and the base electrode of the transistor 220 are connected together directly to the junction 216. The base electrode of the transistor 218 and the emitter electrode of the transistor 220 are connected together directly to a junction 222. A biasing diode 224 is connected between the junction 222 and the ground line 42. The emitter electrode of the transistor 218 is connected directly to the ground line 42. The collector electrode of the transistor 220 is connected directly to the line 128.

The control transistor 214 is of the PNP junction type while the control transistor 215 is of the NPN junction type. The emitter electrode of the transistor 214 is connected directly to the junction 216. The collector electrode of the transistor 214 is connected directly to the ground line 42. The base electrode of the transistor 214 is connected directly to a junction 226. A biasing resistor 228 is connected between the junction 226 and the regulated power line 98. A biasing resistor 230 is connected between the junction 226 and the control pulse line 104. A biasing resistor 231 is connected between the junction 226 and the collector electrode of the transistor 215. The emitter electrode of the transistor 215 is connected directly to the ground line 42.

The discharge current source 210 applies a first constant discharge current I_{d1} to the junction 216. Assuming that the control transistor 215 is turned off, the control transistor 214 is rendered fully conductive in response to the presence of a control pulse C on the control pulse line 104 as sensed through the resistor 230. With the transistor 214 turned on, the first discharge current I_{d1} is effectively shunted through the transistor 214 to the ground line 42. When a control pulse C is terminated on the control pulse line 104, the transistor 214 is rendered fully nonconductive through the biasing action of the resistor 228. With the transistor 214 turned off, the transistors 218 and 220 and the diode 224 of the current sink 212 are rendered conductive. Specifically, the current sink 212 is responsive to the application of the first discharge current I_{d1} through the transistor 218 to draw the same first discharge current I_{d1} from the line 128 through the transistor 220 and the diode 224 to discharge the capacitor 126. Under the influence of the constant first discharge current I_{d1} , the amplitude of the control voltage V defined across the capacitor 126 linearly decreases from the peak voltage level L_p back to the intermediate voltage level L_i over a first discharge time period T_{d1} .

The second discharge circuit 138 includes a differential switch 232 having a sink transistor 234 and a pair of switching transistors 236 and 238 all of the NPN junction type. The collector electrode of the transistor 234 is connected directly to a junction 240 between the emitter electrodes of the transistors 236 and 238. The emitter electrode of the transistor 234 is connected directly to the ground line 42. The base electrode of the transistor 234 is connected directly to a junction 242. A biasing diode 244 is connected between the junction 242 and the ground line 42. A biasing resistor 246 is connected between the junction 242 and the regulated power line 98. A current limiting resistor 248 is connected between the junction 242 and the unregulated power line 40. The base electrode of the transistor 236 is connected directly to the junction 193 in the voltage booster 132. The collector electrode of the transistor 236 and the base electrode of the transistor 238 are connected together directly to the line 128. The collector electrode of the transistor 238 is connected directly to a junction 250. A biasing resistor 252 is connected between the junction 250 and the regulated power line 98.

A buffer switch 254 includes a first transistor 256 of the PNP junction type and a second transistor 258 of the NPN junction type. The base electrode of the transistor 256 is connected directly to the junction 250. The emitter electrode of the transistor 256 is connected directly to the regulated power line 98. A biasing resistor 260 is connected between the collector electrode of the transistor 256 and the base electrode of the transistor 258. A biasing resistor 262 is connected between the base electrode of the transistor 258 and the ground line 42. The emitter electrode of the transistor 258 is connected directly to the ground line 42. The collector electrode of the transistor 258 is connected directly to the base electrode of the transistor 215 in the first discharge circuit 136 at a junction 264. A biasing resistor 266 is connected between the junction 264 and the regulated power line 98.

In the differential switch 232, the transistor 234 provides a constant current sink for the transistors 232 and 238. The transistor 234 is rendered conductive in a

constant current mode through the biasing action of the resistors 246 and 248 and the diode 244 to draw a second discharge period I_{d2} from the junction 240. The magnitude of the second discharge current I_{d2} is defined by the resistors 246 and 248 and the diode 244 in direct proportion to the supply voltage of the vehicle battery 36 as received via the unregulated power line 40. In other words, the magnitude of the second discharge current I_{d2} follows the amplitude of the vehicle battery voltage.

In the conventional manner, the differential switch 232 is operable between a first state and a second state. In the first state, the transistor 236 is rendered fully conductive while the transistor 238 is rendered fully nonconductive. In the second state, the transistor 238 is rendered fully conductive while the transistor 236 is rendered fully nonconductive. The differential switch 232 switches to the first state when the potential at the junction 193 exceeds the potential on the line 128. Alternately, the differential switch 232 shifts to the second state when the potential on the line 128 exceeds the potential at the junction 193. The potential on the line 128 is provided by the control voltage V as defined across the capacitor 126. The potential at the junction 193 is substantially identical to the intermediate voltage level L_i as previously described.

When the amplitude of the control voltage V on the line 128 is above the intermediate voltage level L_i at the junction 193, the differential switch 232 shifts to the second state in which the transistor 238 is rendered fully conductive and the transistor 236 is rendered fully nonconductive. With the transistor 238 turned on, the transistor 256 is rendered fully conductive through the biasing action of the transistors 234 and 238. With the transistor 256 turned on, the transistor 258 is rendered fully conductive through the biasing action of the resistors 260 and 262. With the transistor 258 turned on, the transistor 215 in the first discharge circuit 136 is rendered fully nonconductive through the biasing action of the transistor 258. With the transistor 215 turned off, the operation of the first discharge circuit 136 is as priorly set forth.

As the amplitude of the control voltage V defined across the capacitor 126 decreases from the peak voltage level L_p back toward the intermediate voltage level L_i , the differential switch 232 remains in the second state. When the amplitude of the control voltage V arrives back at the intermediate voltage level L_i , the differential switch 232 switches to the first state in which the transistor 236 is rendered fully conductive and the transistor 238 is rendered fully nonconductive. With the transistor 238 turned off, the transistors 256 and 258 are likewise rendered fully nonconductive. With the transistor 258 turned off, the control transistor 215 in the first discharge circuit 136 is rendered fully conductive through the biasing action of the resistor 266. With the transistor 215 turned on, the transistor 214 is rendered fully conductive through the biasing action of the transistor 215 and the resistor 231. With the transistor 214 turned on, the first discharge current I_{d1} is again shunted through the transistor 214 to the ground line 42.

Further, with the transistor 236 turned on, the second discharge current I_{d2} drawn from the junction 240 through the transistor 234 is also drawn from the line 128 through the transistor 236 to further discharge the capacitor 126. Under the influence of the constant sec-

ond constant discharge current I_{d2} , the amplitude of the control voltage V linearly decreases from the intermediate voltage level L_i back to the base voltage level L_b over a second discharge time period T_{d2} . As the control voltage V arrives back at the base voltage level L_b , the differential switch 140 shifts to the first state to terminate the injection pulse I on the injection pulse line 86 at the junction 172. At this point, the entire control pulse stretcher 94 is in condition to develop another injection pulse I in response to the initiation of the next control pulse C.

As shown in FIG. 3, the temperature sensor lines 106, 108 and 110 are connected to the charge current source 200 for defining the charge current I_c in inverse relation to the intake air temperature as sensed by the thermistor 112, in inverse relation to the engine coolant temperature as sensed by the thermistor 114, and in direct relation to the injected fuel temperature as sensed by the thermistor 116. Alternately, the temperature sensor lines 106, 108 and 110 may be connected to the discharge current source 210 for defining the first discharge current I_{d1} in direct relation to the intake air temperature, in direct relation to the engine coolant temperature, and in inverse relation to the injected fuel temperature. Between the extremes of these two examples, it will be apparent that either the charge current I_c or the first discharge current I_{d1} may be appropriately varied in response to any desired combination of the intake air temperature, the engine coolant temperature, and the injected fuel temperature. The charge current source 200 and the discharge current source 210 may be provided by virtually any suitable thermistor controlled constant current sources.

As previously described, the fuel injector driver 88 energizes the fuel injector 48 for the duration T_i of the injection pulses I emitted by the control pulse stretcher 94. The total quantity of fuel Q delivered to the engine 10, which is proportional to the duration T_i of the injection pulses I, may be expressed by the following equation:

$$Q \propto T_p + T_s \quad (1)$$

which indicates that the fuel quantity Q is equal to the primary time period T_p plus the secondary time period T_s . The secondary time period T_s may be expressed by the following equation:

$$T_s = T_{d1} + T_{d2} \quad (2)$$

which indicates that the secondary time period T_s is equal to the first discharge time period T_{d1} plus the second discharge time period T_{d2} . The first discharge time period T_{d1} may be expressed by the following equation:

$$T_{d1} = T_p(I_c/I_{d1}) \quad (3)$$

which indicates that the first discharge time period T_{d1} is equal to the primary time period T_p multiplied by the ratio I_c/I_{d1} of the charge current I_c to the first discharge current I_{d1} . The second discharge time period T_{d2} may be expressed by the following equation:

$$\tau_{d_2} = (L_i - L_b) C / I_{d_2} \quad (4)$$

which indicates that the second discharge time period T_{d_2} is equal to the time interval defined between the decrease of the control voltage V from the intermediate level L_i to the base level L_b as a result of discharging the capacitance C of the capacitor 126 with the second constant discharge current I_{d_2} . The simultaneous solution of equations 1-4 for the fuel quantity Q yields the following equation:

$$Q \neq T_p(I_c/I_{d_1}) + (L_i - L_b) C / I_{d_2} \quad (5)$$

which defines a linear or straight-line fuel control curve F as shown in FIG. 4.

Referring to FIG. 4, the fuel control curve F is described within a two-dimensional coordinate system defined by a horizontally disposed X-axis and a vertically disposed Y-axis which perpendicularly intersect at an origin O . The primary time period T_p , which is defined as a preselected function of the air pressure within the intake manifold 20, is plotted along the X-axis. The fuel quantity Q is plotted along the Y-axis. The fuel control curve F is characterized by a slope and an offset. The slope of the fuel control curve F is given by the ratio (y'/x') of the distance y' traced along the Y-axis to the distance x' traced along the X-axis when an imaginary point is moved a distance a along the fuel control curve F . The offset of the fuel control curve F is given by the distance b lying between the origin O and the intersection U of the fuel control curve F with the Y-axis. This intersection is only theoretical since the primary time period T_p is never zero in actual practice.

Referring to equation 5, the slope of the fuel control curve F is defined by the term I_c/I_{d_1} . Changes in the slope term, which are defined as a preselected function of a temperature of the engine 10, have the effect of rotating the fuel control curve F about the Y-axis intercept U as depicted by the double-headed arrow 268. The offset of the fuel control curve F is defined by the term $(L_i - L_b) C / I_{d_2}$. Changes in the offset term, which are defined as a preselected function of the supply voltage of the vehicle battery 36, have the effect of vertically shifting the Y-axis intercept U of the fuel control curve F as depicted by the double-headed arrow 270. Since the intermediate level L_i is greater than the base level L_b , the resultant sign of the offset term $(L_i - L_b) C / I_{d_2}$ is always plus (+). Accordingly, the Y-axis intercept U of the fuel control curve F cannot be shifted below the origin O .

The net change in the amount of fuel delivered to the engine 10 as a result of variations in the temperature of the engine 10 is dependent upon the pressure of the air within the intake manifold 20. Given a constant air mass within the intake manifold 20, the intake air pressure is directly proportional to the air intake temperature. Further, the amount of fuel condensation and the amount of fuel vaporization are directly proportional to the quantity of fuel injected into the intake manifold 20 as principally determined by the intake air pressure. Thus, as engine operating temperature, the intake air temperature, the engine coolant temperature, and the injected fuel temperature are multiplicatively related to the intake air pressure. Consequently, the slope (y'/x')

of the fuel control curve F should be a function of these various engine temperatures only. This criteria is satisfied by the slope term I_c/I_{d_1} of equation 5.

The net change in the amount of fuel delivered to the engine 10 as a result of variations in the supply voltage of the vehicle battery 36 is independent of the pressure of the air within the intake manifold 20. Hence, as engine operating parameters, the battery supply voltage is additively related to the intake air pressure. Therefore, the offset b of the fuel control curve F should be a function of the vehicle battery voltage only. This criteria is satisfied by the offset term $(L_i - L_b) C / I_{d_2}$ of equation 5 in which only the second discharge current I_{d_2} is varied in response to the battery supply voltage.

It is to be noted that the illustrated embodiment of the invention is shown for demonstrative purposes only and that various alterations and modifications may be made to the illustrated embodiment without departing from the spirit and scope of the invention.

What is claimed is:

1. In an internal combustion engine, the combination comprising: a capacitor for developing a control voltage thereacross; means for charging the capacitor with a charge current in synchronization with the operation of the engine to increase the control voltage from an intermediate level to a peak level over a charge time period; means responsive to the arrival of the control voltage at the peak level for discharging the capacitor with a first discharge current to decrease the control voltage from the peak level back to the intermediate level over a first discharge time period; means responsive to the arrival of the control voltage back at the intermediate level for further discharging the capacitor with a second discharge current to decrease the control voltage from the intermediate level to a base level over a second discharge time period; means for defining at least one of the peak level and the charge time period as a preselected function of a primary engine operating parameter; means for defining at least one of the charge current and the first discharge current as a preselected function of a secondary engine operating parameter multiplicatively related to the primary engine operating parameter; means for defining at least one of the second discharge current and the intermediate level and the base level as a preselected function of a secondary engine operating parameter additively related to the primary engine operating parameter; and means for applying fuel to the engine in an amount determined by the time interval established between the initial departure of the control voltage from the intermediate level and the ultimate arrival of the control voltage at the base level so that the total quantity of fuel delivered to the engine is defined in relation to the preselected function of the primary engine operating parameter by a linear fuel control curve having a slope determined by the preselected function of the secondary engine operating parameter multiplicatively related to the primary engine operating parameter and having an offset determined by the preselected function of the secondary engine operating parameter additively related to the primary engine operating parameter.

2. In an internal combustion engine, the combination comprising: means for producing a control pulse initiated in synchronization with the operation of the engine and terminated after the expiration of a primary time period T_p defined as a preselected function of a

primary engine operating parameter; a capacitor having a capacitance C for developing a control voltage thereacross; means for charging the capacitor with a charge current I_c in response to the initiation of the control pulse to increase the control voltage from an intermediate level L_i to a peak level L_p at the termination of the control pulse; means for discharging the capacitor with a first discharge current I_{d1} in response to the termination of the control pulse to decrease the control voltage from the peak level L_p back to the intermediate level L_i ; means for discharging the capacitor with a second discharge current I_{d2} in response to the arrival of the control voltage back at the intermediate level L_i to decrease the control voltage from the intermediate level L_i to a base level L_b ; means for applying fuel to the engine in an amount determined by the time interval established between the initial departure of the control voltage from the intermediate level L_i and the ultimate arrival of the control voltage at the base level L_b so that the total quantity of fuel Q delivered to the engine is defined by the following equation

$$Q = T_p(I_c/I_{d1}) + (L_i - L_b) C/I_{d2};$$

means for defining at least one of the charge current I_c and the first discharge current I_{d1} as a preselected function of a secondary engine operating parameter multiplicatively related to the primary engine operating parameter; and means for defining at least one of the second discharge current I_{d2} and the intermediate level L_i and the base level L_b as a preselected function of a secondary engine operating parameter additively related to the primary engine operating parameter.

3. In an internal combustion engine including an air supply system for providing intake air to the engine, a battery for providing a supply voltage, and a fuel supply system including at least one voltage responsive fuel in-

jector for applying fuel to the engine when energized by the supply voltage, the combination comprising: means for producing a control pulse initiated in synchronization with the operation of the engine and terminated at the expiration of a primary time period T_p defined as a preselected function of the pressure of the intake air; a capacitor having a capacitance C for developing a control voltage thereacross; means responsive to the initiation of the primary control pulse for charging the capacitor with a charge current I_c to increase the control voltage from an intermediate level L_i to a peak level L_p at the termination of the control pulse; means responsive to the termination of the primary control pulse for discharging the capacitor with a first discharge current I_{d1} to decrease the control voltage from the peak level L_p back to the intermediate level L_i ; means responsive to the arrival of the control voltage back at the intermediate level L_i for further discharging the capacitor with a second discharge current I_{d2} to decrease the control voltage from the intermediate level L_i to a base level L_b ; means for energizing the fuel injector with the supply voltage between the initial departure of the control voltage from the intermediate level L_i and the ultimate arrival of the control voltage at the base level L_b so that the total quantity of fuel Q applied to the engine is defined by the following equation

$$Q = T_p(I_c/I_{d1}) + (L_i - L_b) C/I_{d2};$$

means for defining at least one of the charge current I_c and the first discharge current I_{d1} as a preselected function of a temperature of the engine; and means for defining at least one of the second discharge current I_{d2} and the intermediate level L_i and the base level L_b as a preselected function of the magnitude of the supply voltage.

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