

[54] **ELECTRONIC ENERGIZING SYSTEM FOR SOLENOID FUEL INJECTORS**

[75] Inventor: Allen W. Lindberg, St. Louis, Mo.

[73] Assignee: ACF Industries, Incorporated, New York, N.Y.

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[51] Int. Cl. F02m 51/06, F02b 3/00

[58] Field of Search 317/DIG. 5;
123/32 EA, 119 R

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Primary Examiner—Laurence M. Goodridge

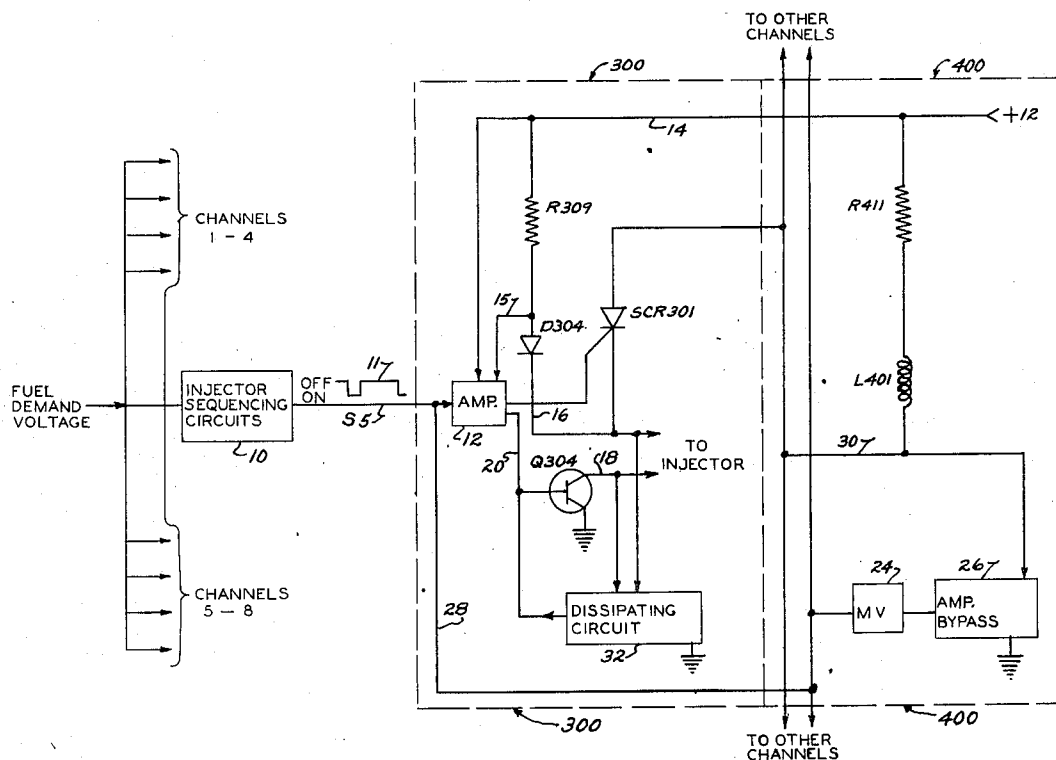
Attorney—Edward H. Casey

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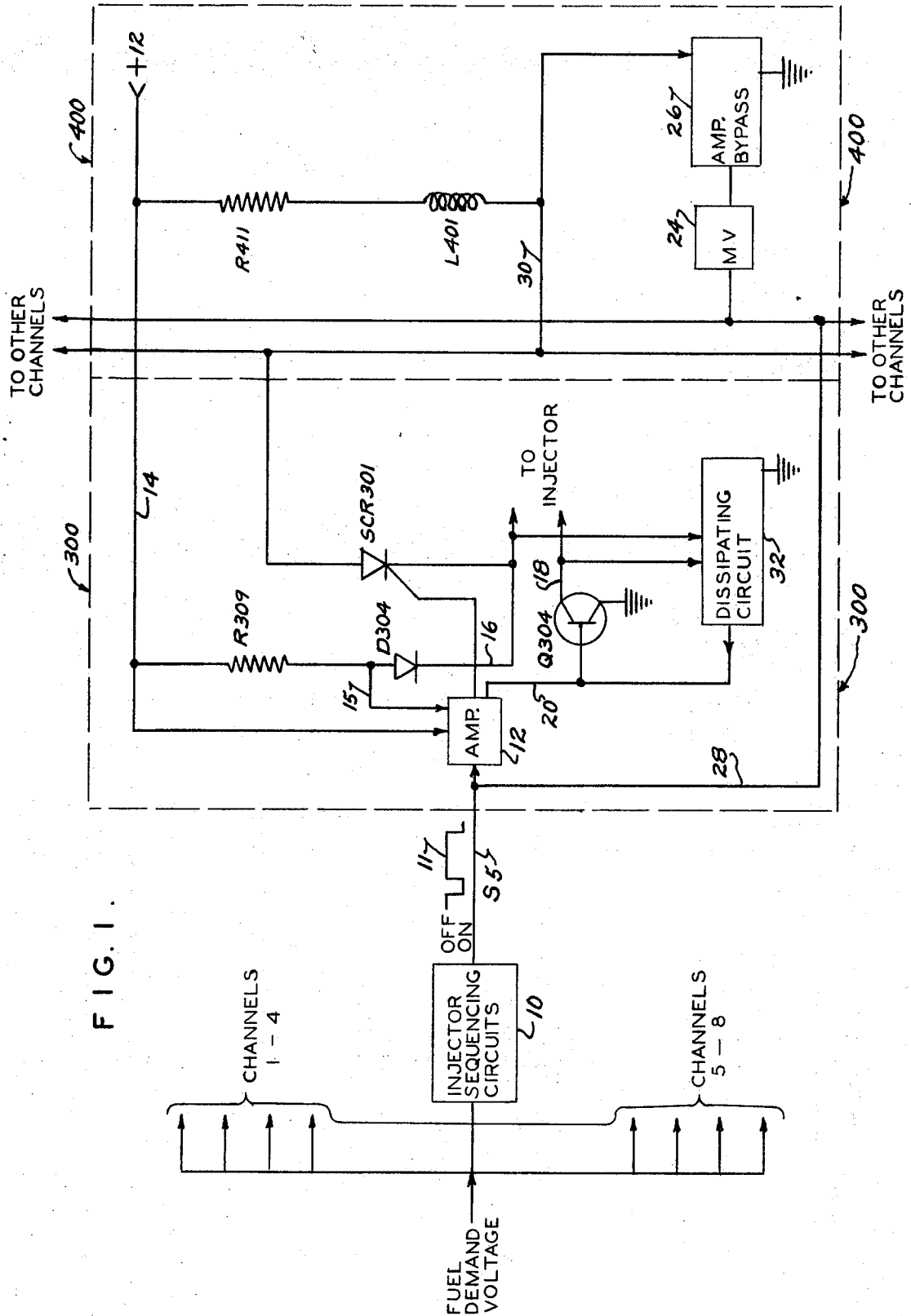
ABSTRACT

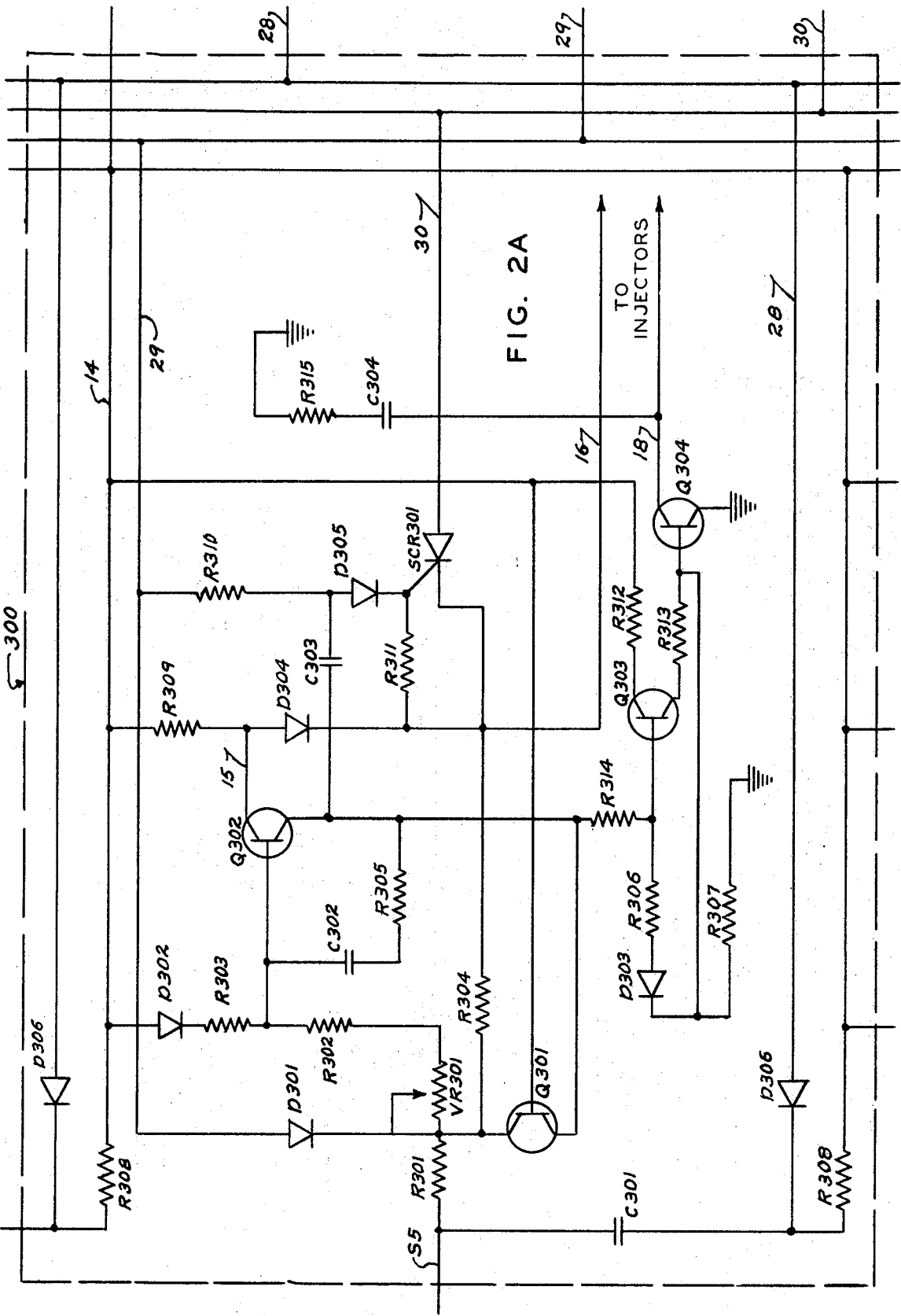
A system for energizing solenoid valve injectors sequentially, includes a separate channel for each injector on which synchronized fuel demand pulses are impressed. Each channel includes a transistor connecting one terminal of its injector to ground and a control circuit responsive to the input pulses for making said transistor conductive. The other terminal of the injector is connected to a stabilized source of voltage capable of supplying a holding current to the injector, and said terminal of the injector is also connected through a silicon controlled rectifier to an inductor. The inductor is common to all channels, and circuitry responsive to the fuel pulses enables the inductor to supply a high starting current in response to the beginning of each fuel pulse to cause rapid opening of the solenoid injectors and then permit the injector current to drop approximately to the holding level. Another circuit rapidly dissipates the injector current at the end of a fuel pulse.

7 Claims, 3 Drawing Figures



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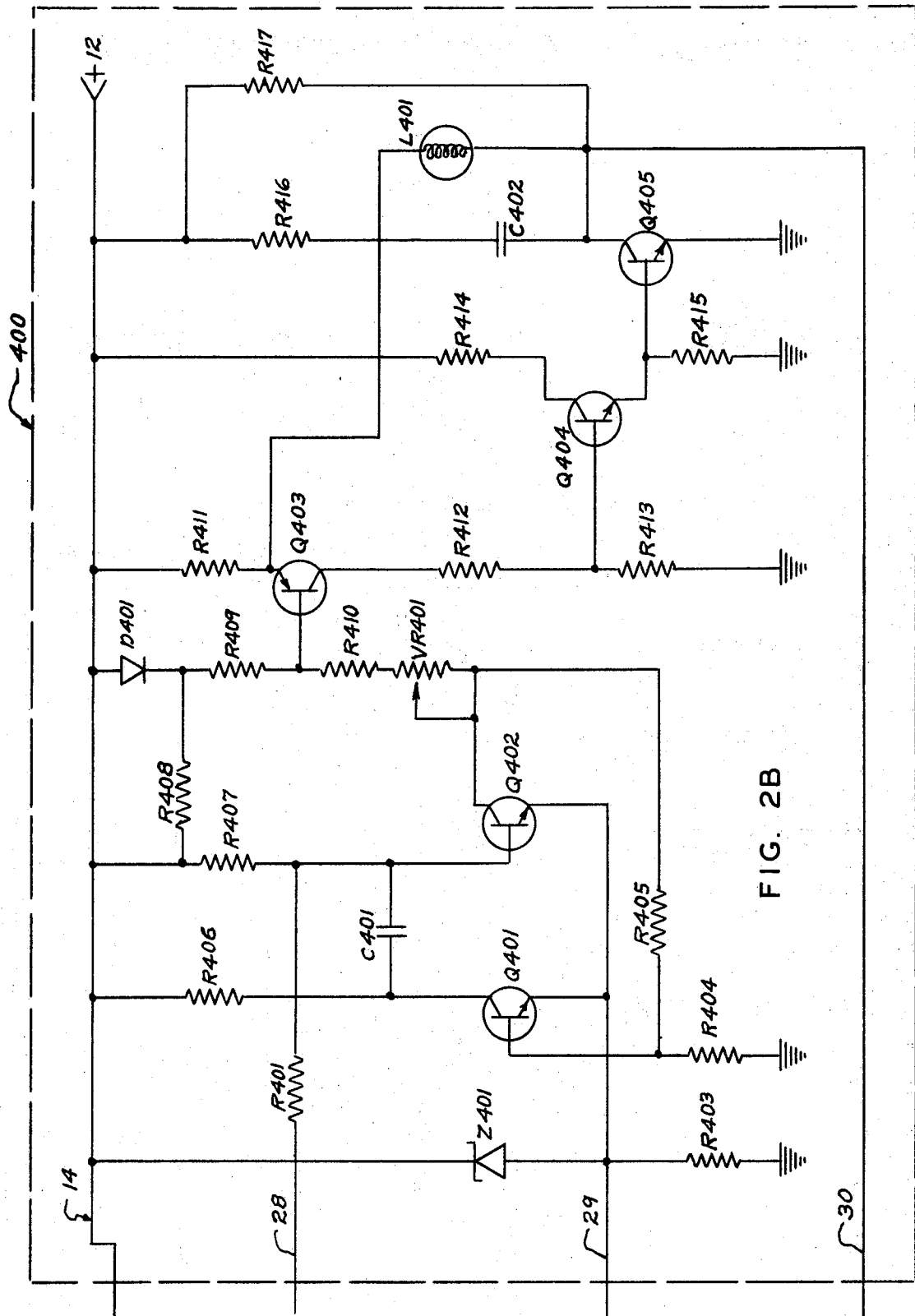


FIG. 2B

ELECTRONIC ENERGIZING SYSTEM FOR SOLENOID FUEL INJECTORS

BACKGROUND OF THE INVENTION

Sequential fuel injection systems have been proposed in which the injectors are operated successively. At very high speeds the injectors must remain open for long periods in order to supply the large amount of fuel required. This is a limiting factor, since at high engine speeds the fuel injectors must be operated in rapid succession and only a very short interval of time is available for each injector. It is an object of this invention to overcome this difficulty by enabling the periods of injector operation to overlap. Another known difficulty of electronic fuel injection systems using solenoid actuated injectors is that the periods of injection vary among the different injectors owing to variations in their structure, and other factors. Another object of this invention is to enable the injectors to open very rapidly in order to minimize variations in the time of opening relative to the beginning of a fuel injection pulse. Still another object of the invention is to reduce variations in the time of closing of the injectors.

SUMMARY OF THE INVENTION

A sequential electronic fuel injection system is provided having a separate channel for each cylinder. Each channel includes the injector and a controlled circuit responding to sequential fuel demand pulses for energizing each injector. The circuit includes temperature and voltage stabilized transistors for supplying current to the injectors for periods equal to the duration of the fuel injection pulses. An inductor is connected at one terminal thereof to a stabilized voltage source and has its other terminal normally grounded by a transistor. A monostable multivibrator responds to each fuel pulse to cut off the last-mentioned transistor and transfer momentarily the current of the inductor to the proper injector to cause it to open very rapidly. After a very short interval, the multivibrator reverses and the inductor is again effectively grounded through the transistor. The current from the inductor is fed to each injector through a silicon controlled rectifier in each channel. The silicon controlled rectifier is gated ON in response to the beginning of each fuel injection pulse for that channel. After the rectifier is turned off, the current through the injector falls to a relatively low level and this minimizes variations in the time of closing of the injectors. A dissipative circuit rapidly terminates the injector current at the end of a fuel demand pulse.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a simplified diagram of the injection system showing the elements for energizing one injector.

FIG. 2 is a detailed circuit diagram consisting of FIGS. 2A and 2B.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is made to the drawing and particularly to FIG. 1, which is a simplified diagram of the invention applied to an eight cylinder engine. Injector sequencing logic circuits 10, one for each cylinder, produce rectangular fuel demand pulses 11 synchronized to the respective cylinders. The pulses have a negative logic, that is, the low portions thereof are the ON pulses and the high portions are OFF pulses. The duration of an

ON pulse is equal to the period of fuel injection and proportional to the fuel demand determined by suitable engine sensors. FIG. 1 only shows the channel for cylinder No. 5, which includes an injector operating unit 300 and starting pulse circuit 400. The fuel pulses from circuit 10 are impressed on the input of amplifier 12, which has a negative current feedback connection 15 and is connected by line 14 to a stable voltage source. The amplifier is a complex multi-stage circuit which will be described with reference to FIG. 2. Substantially the full voltage of line 14 is supplied through elements R309, D304 and line 16 to one side of the injector, which is a solenoid actuated valve connected to the fuel supply line, as is conventional. However, no current flows through the injector during the OFF period, because the return line 18 of the injector includes transistor Q304, which is biased off by output line 20 of amplifier 12, and because the same output of amplifier 12 is applied to gate 22 of controlled rectifier SCR301 to bias it off.

During the fuel pulse ON period, amplifier 12 is switched ON and makes transistor Q304 conductive. Current then flows through line 14, 16, the injector, line 18 and transistor Q304, thereby opening the injector during the ON pulses. In order to obtain more rapid and, therefore, more precise opening of the injectors, an additional high current is momentarily supplied to each injector to start its opening. This is done with injector starting pulse source 400, which includes monostable multivibrator 24, amplifier and bypass unit 26, inductor L401, and resistor R411. Fuel pulses 11 are fed over line 28 to delay multivibrator 24. In the OFF condition, current flows from line 14 through R411 and L401, and is bypassed to ground by the last stage of unit 26, which is made conductive by multivibrator 24. No current flows to the injector through SCR301 since it is gated OFF and Q304 is not conductive. At the beginning of an ON pulse, transmitted over line 28, multivibrator 24 changes to its ON state for a brief period of about one millisecond, and turns circuit 26 off, and at the same time amplifier 12 turns SCR301 and Q304 on, and thus the current in inductor L401 continues to flow, passing through SCR301, the injector, and Q304. The large additional current pulse delivered by L401 to the injector at the beginning of an ON pulse lasts only long enough to cause rapid opening of the injector. Thereafter, multivibrator 24 reverts to its OFF condition and makes the output of circuit 26 conductive to effectively ground line 30 and the anode of SCR301 to cut it off and terminate current flow from inductor L401 to the injector. For the remainder of the ON pulse, the injector is held open only by the current supplied through R309, D304 and line 16. Amplifier 12 is stabilized by negative feedback connection 15 so that the holding current supplied to the injector is precisely regulated, to enable amplifier 12 to turn off the injector quickly at the end of the ON pulse. In the described manner the single power pulse supply unit 400 is actuated by the injector operating unit 300 of each channel in proper sequence for supplying a very short duration high current pulse to the injector of that channel at the beginning of each ON pulse.

Circuit 32 dissipates the injector solenoid current at the end of each fuel demand pulse.

An example of circuitry suitable for generating pulses 11 for the several channels is shown in my Patent application Ser. No. 208,633, filed Dec. 16, 1971.

Reference is now made to FIG. 2. The injector sequencing logic circuit 10 generates an injector ON pulse for each injector. The signal wires, such as S5, carry these injector command signals. The command is inverted (negative logic), so that when S5, for example, is high (approximately battery voltage), the related injector is OFF; and when the signal is low (nearly to ground voltage), the injector is ON.

Operation is described with reference to the No. 5 channel. When signal 11 is high, D301 and D302 are not conducting and Q302 is off. Diode D305 is reverse biased and SCR301 is off, Q301 is off and no current flows in R314. Q303 is off and so is Q304. The injector current, therefore, is zero.

When signal 11 goes low, R301 conducts and D301 and D302 become forward biased and conduct. The value of the resistors R301, R302, R303 and variable resistor VR301 are such that D301 begins to conduct when S5 is several volts above ground, and therefore the current flowing through R303, R302 and VR301 is not dependent on the exact voltage on S5. These resistors R303, R302, and VR301 form a voltage divider which turns on Q302 with an accurately controlled voltage. This voltage includes the injector current command, which is the voltage developed across R303 and a temperature compensation signal which is the ON or forward bias voltage of D302 and D301. The voltage across these diodes has the same temperature coefficient as the input (emitter-base) voltage of Q302. This provides temperature compensation to an adequate degree of precision. Also, because of the clamping action of diodes D301 and D302, the voltage across the said voltage divider is equal to the voltage across zener diode Z401, of nominally five volts, impressed on D301 and D302 by lines 29 and 14.

Neglecting for the moment, the action of the starting pulse circuit 400, when S5 goes low as described, and noting that R309 is only 1 ohm nominal, Q302 turns on strongly, and this turns on Q303 and then Q304. With Q304 ON, current starts to flow in the injector. Because of the high amount of gain in the circuit, Q304 is saturated. Its base current is limited by R312. Therefore, nearly full battery voltage is applied to the injector. The current which flows passes through D304 and R309. R309 is a current measuring shunt and provides a negative current feedback signal for the control. Therefore, when the injector current flowing makes a voltage drop in R309 nearly equal to the voltage drop in R303, the amplifier is balanced and that amount of current is maintained as long as the voltage at S5 is low. In order to maintain a high degree of stability of this maintained current over a wide range of operating temperatures, it was found desirable to provide temperature compensation for the second stage of amplification Q303. This is provided by R313, R307, R306 and D303. R314 and R312 are current limiters to protect the circuit during saturated operation.

The maintained current which is provided by the control holds the injector ON and because this current is precisely regulated, the accuracy of control in turning the injection off is improved. In turning off the injector when S5 goes high, Q304 turns off instantaneously. Because the injector is inductive, the current must be decreased in an orderly manner. With Q304 off, the injector current flows into C304, through R315, the battery, R309, D304, and into the other injector terminal. As this current flows, some of the en-

ergy is dissipated in the circuit resistance and the rest is transferred to C304. As this resonant current reaches the first zero crossing (one-half cycle of the resonant frequency), D304 becomes reverse biased and injector current stays at zero. The charge which is stored on C304 is quickly dumped in the following manner: With no further current flow in the injector, the C304 charge is impressed through the injector on R304 to turn on Q301. The signal from Q301 is amplified and turns on Q304, to dissipate the charge. Most of the energy is dissipated in R315.

There are other ways of obtaining an orderly current delay in the injector. However, the advantage of doing it in the said way is that the maximum rate of change of current occurs as the current reaches zero. Since the mechanical motion is assumed to begin just prior to the current zero crossing, the variations in actual value of drop out current have less effect on total drop out time delay.

Thus, the injector main control 300 is a stabilized current driver with the addition of a controlled current decay feature. Because the circuit is a high gain feedback amplifier, some consideration must be given to circuit dynamic stability. In this respect, C302 and R305 provide a filtering function to make the circuit stable.

The injector main control also includes initiating and multiplex switching circuits to work in harmony with the injector pulse power source 400.

Capacitor C301, D306, and R308 provide a negative input pulse to the pulse power source 400 at the leading edge of the injector ON pulse. Each injector channel provides a similar pulse, all added together at the input R401 to the pulse power source. In this way pulse power source 400 is operated at the leading edge of each injector ON pulse. Multiplexing of the output of the injector pulse power source is done with the silicon controlled rectifiers SCR301 and related parts. When S5 goes low (injector ON command) Q302 turns full on as was previously described. The leading edge of this positive transition is coupled to the gate of SCR301 by C303, D305, and R311. This SCR then switches the positive output from the pulse power supply 400 back into the same injector main control which initiated the power pulse.

This positive pulse, switched through SCR301 reverse-biases D305 and D304, flows through the injector, through Q304 to ground. Because D304 is reverse-biased, no current is flowing in R309 and the amplifier stages remain saturated by the S5 signal. Additionally, if S5 should go high (OFF) any time during a power pulse, it is important to keep Q304 saturated. To do this, the positive pulse is coupled through R304 to turn Q301 and through amplifier Q303 to keep Q304 saturated. It is important for reasons of cost and reliability that Q304 not be used to modulate either turn-on or turn-off pulses because of the second breakdown power limitations of those transistors.

Pulse power source 400 is designed to maintain a calibrated "charge" condition of inductance L401 and then, on command, switch that inductance into the injector circuit. To do this, a current driver is provided. This driver is a high gain current feedback amplifier composed of Q403, Q404, Q405, and related parts. Its operation is similar to that of the amplifier composed of Q302, Q303, Q304, and related parts.

Current driver Q403, Q404, Q405 is maintained in a normally ON state by the signal from a time delay circuit Q401, Q402. In this time delay circuit, Q402 is maintained in saturated ON condition by bias from R407. This turns on a voltage divider made up of VR401, R410, R409 and D401. The input to this divider is the zener voltage Z401, and D401 provides temperature compensation for Q403.

Q401 is coupled to Q402 to form a delay multivibrator circuit. So long as Q402 is ON, Q401 is OFF. The occurrence of a negative input pulse, as described, causes current flow through R401 which momentarily turns off Q402. Current through R405 turns on Q401, and through C401 holds Q402. Current through R407 discharges C401 until Q402 begins to conduct, again, at which time the circuit reverts to its normal state. The time that the multivibrator is in its abnormal state is determined by C401 and R407. This time has generally been set to about one millisecond, but the best adjustment relates to the injector design.

When circuit 400 is in its abnormal state, Q403 is off as are Q404 and Q405. As Q405 turns off, the current flowing in L401 continues to flow and forms the injector opening power pulse. The peak voltage generated by this pulse is limited by R417 and the injector load. Because of the high peak power involved, the rate of rise of the pulse must be controlled to avoid second breakdown destruction of Q405. This rate of rise is controlled by C402 and R416. The pulse power supply has typically been operated at current levels of two to three amperes.

Thus, the system disclosed herein is capable of providing a wide range of fuel rate injection by precisely actuated solenoid fuel injectors operating sequentially.

In particular, each injector can be opened precisely on schedule and closed precisely on schedule, even under those conditions where the injector second, or even third, in the sequence is opened before the first solenoid has closed. The aforementioned ability for overlapping is of material benefit in controlling the accuracy of fuel metered during any one opening and closing cycle of a given injector.

What is claimed is:

1. An electronic fuel injection sytem, comprising a solenoid valve injector, a stabilized voltage source, a normally blocked first transistor, switching means connected in series with said transistor and said injector, means for supplying fuel demand voltage pushes having a duration substantially equal to the required time of opening of the injector, an inductor connected in series with said voltage source and having one end thereof normally grounded and also connected to said switching means, and control means responsive to a fuel demand pulse for rendering said first transistor and switching means conductive and causing said inductor to supply a high power pulse to the injector for opening it rapidly.

2. A system according to claim 1, including means for terminating said high power pulse after a fixed interval which is short compared to the duration of a fuel demand pulse.

3. A system according to claim 2, wherein said means for terminating the high power pulse includes a second transistor connecting said one end of the inductor to ground, said second transistor being normally conductive.

4. A system according to claim 3, including a monostable multivibrator connected to said second transistor for controlling the conductivity thereof.

5. A system according to claim 4, wherein said multivibrator is responsive to the beginning of a fuel demand pulse for blocking said second transistor during the opening of the injector.

6. A system according to claim 1, wherein said switching means includes a silicon controlled rectifier having its anode connected to the inductor and its cathode connected to the injector.

7. A system according to claim 1, including an amplifier responsive to a fuel demand pulse for controlling the conductivity of said first transistor, and means responsive to injector current for supplying a negative feedback current to said amplifier for stabilizing the current supplied to said injector at a value slightly greater than the holding current thereof.

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