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(54) Title: A SECONDARY FUELLING SYSTEM AND A METHOD OF CONTROLLING SECONDARY FUELLING IN AN
INTERNAL COMBUSTION ENGINE

(57) Abstract: The invention concerns a secondary fuelling system for fitting to an internal combustion engine, the internal combustion engine being configured to be fuelled with a primary fuel and the secondary fuelling system being configured to supply a controlled quantity of a secondary fuel, in addition to the primary fuel, to a combustion chamber of the engine. The secondary fuelling system is configured to determine an engine parameter indicative of quantity of primary fuel supplied to the combustion chamber, to calculate a required quantity of secondary fuel to be supplied to the combustion chamber as a function of the monitored engine parameter, and to supply the required quantity of secondary fuel to the engine. In certain embodiments the secondary fuelling system carries out the determination of the engine parameter and the calculation of the required quantity of secondary fuel during each engine cycle and in that the required quantity of secondary fuel determined in one engine cycle is supplied to the combustion chamber in the same engine cycle or in the following engine cycle.



DESCRIPTION**A SECONDARY FUELLING SYSTEM AND A METHOD OF
CONTROLLING SECONDARY FUELLING IN AN INTERNAL
COMBUSTION ENGINE**

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This invention relates to a secondary fuelling system for an internal combustion engine, and to a method of controlling secondary fuelling of an internal combustion engine.

Conventional internal combustion engines comprise a piston that reciprocates within a cylinder and a crank mechanism for converting the reciprocating movement of the piston into a rotational output for useful work. Other types of internal combustion engine, such as the rotary Wankel engine, are known. The operation and efficiency of an internal combustion engine depends on a great number of factors, including the type and mixture of fuel used, the compression ratio, the dimensions of the piston/cylinder, etc.

There is a known practice of retro-fitting internal combustion engines made to run on conventional oil-based fuels – in particular petrol (gasoline) or diesel – with a secondary fuelling system to supply a different fuel in addition, or sometimes as an alternative, to the primary fuel. Typically such “dual fuelling” systems belonging to the prior art have sought to maximize the quantity of the secondary fuel. For example petrol engines are converted to be fuelled using 100% gas. Diesel engines are converted to be fuelled typically in the range 20-99% gas. Gas is a less expensive form of fuel, so maximising its usage minimises fuel cost.

A different approach is to introduce a relatively small quantity of a secondary fuel in order to improve overall fuel efficiency of the engine. It is known that the efficiency of a conventional internal combustion engine running on a primary fuel such as diesel or petrol (gasoline) is improved by supplying to the engine’s combustion chamber(s) a controlled quantity of a secondary fuel. Typically the secondary fuel is of higher octane value than the primary

30

fuel. The reasons why such secondary fuelling systems offer efficiency benefits are complex.

The speed and completeness of the burn is one of the main factors that determine the overall efficiency of the engine. Combustion occurs during the
5 'power' stroke of the piston which has a fixed length and profile. For 100% combustion efficiency, all the fuel would be combusted homogenously producing only water and carbon dioxide. In practice this is a 'chain' reaction initiated by a spark (spark ignition engine) or by heat generated by compression (compression ignition engine). Hydrocarbon fuels such as
10 diesel have a molecular structure which is long, complex and slow to combust. These long hydrocarbons have a tendency to tangle and/or accumulate together, preventing efficient mixing of the fuel with the air or oxygen. Diesel fuel in particular, being burnt in an enclosed chamber that is externally cooled, will ignite towards the centre of the chamber and the burn
15 will progress outward at a slow rate. In the case of diesel engines this is largely responsible for smoke and particulate matter issuing from the exhaust system of the engine.

Factors that affect the proportion of available fuel that is burnt include:

- (i) The molecular chain length of the fuel itself - the longer the
20 chain length, the less likely it is that complete combustion will occur in a given time frame;
- (ii) The dimensions of the cylinder - the larger the volume, the longer it will take for the "flame front" to reach the boundaries of the cylinder, which for large dimensions or slow "flame fronts" may never occur; and
- 25 (iii) The time available for combustion, which varies with engine speed.

The amounts of fuel and time available for combustion are limited according to engine load and piston speed (RPM). Within the enclosed cylinder there are typically 'hot' and 'cold' regions, particularly around the
30 cooled cylinder walls. In regions where there is no hydrocarbon for the

oxygen to react, the oxygen reacts with nitrogen to produce NO_x. In areas deficient of oxygen incomplete combustion will occur resulting in CO. In 'cool' areas where the chain combustion reaction has stopped there will be un-combusted fuel and air entering the exhaust phase. This also applies to
5 rotary engines such as Wankel engines.

LPG (liquefied petroleum gas) is one readily available higher octane fuel that is used as an additive or secondary fuel(s) in order to improve the combustion of a lower octane primary fuel such as diesel or petrol (gasoline). In a diesel engine, petrol (gasoline) may itself be used as a secondary fuel,
10 being of higher octane value.

While the present invention is not reliant on any particular explanation of the effects of secondary fuelling, it is suggested that in suitable secondary fuel systems a small amount of the secondary fuel serves to improve the combustion of the primary fuel. The flame front velocity is higher for shorter
15 length molecules of the secondary fuel and increases the flame front velocity for the secondary fuel overall, thus accelerating the combustion of the combined fuels. The combustion is faster, allowing more time for combustion even in the 'cold' regions during the power stroke. Fuel which would, in a conventional engine, remain un-burnt and pass to the exhaust is, in a
20 suitable secondary-fuelled engine, be burnt during the power stroke and contribute to engine output power. Engine efficiency is increased and the HC and particulate matter emissions are significantly reduced because more of the available fuel is combusted.

The inventor has recognised an additional way in which fitting a suitable
25 secondary fuelling system improves the efficiency of an existing internal combustion engine. This relates to ignition/injection timing and engine knock. It is well known that advancing ignition of the fuel in the combustion chamber offers potential efficiency benefits. However excessive advance of fuel ignition causes deleterious engine knocking, limiting the degree to which fuel
30 ignition is advanced. Secondary fuel in principle serves as a knock inhibitor,

allowing combustion to take place earlier in the engine cycle without knocking and so improving energy efficiency. The combined fuel has an increased Research Octane Number (RON) compared to the primary fuel alone.

5 The present inventor has further recognised that in engines equipped with suitable engine management systems the required adjustment of engine timing takes place automatically following installation and activation of a secondary fuel supply system, without replacement or adjustment of the factory fitted engine management. Modern diesel engines are typically fitted
10 with a knock sensor and have an ECU which will suitably adjust and optimise fuel injection timing provided that the secondary fuel is supplied in a manner sufficiently consistent for such adjustment to take place. To this end it is desirable that the properties of the combined fuel should be consistent from one engine cycle to the next.

15 In diesel engines the diesel is injected in a series of pulses often described as Pilot Pulse, Main Pulse and End pulse – often three or more pulses are used. Modern diesel engines have injection technology using a Pilot injection pulse that is often advanced more than 35 degrees from TDC (top dead centre) in order to improve the efficiency and emissions of the
20 diesel engine. When replacing the diesel with significant amount of high octane fuels such as LPG/CNG/LNG/H and where combustion is initiated at these timings of TDC advance this will in itself cause the engine to knock unless the additive fuel is also injected as a multi-burst sequence as per the diesel fuel. For example in a gas or petrol engines the ignition spark is timed
25 typically between 10 – 20 degrees TDC advance; increasing this advance is a cause of engine knock. Thus the level of high octane fuel secondary that is injected as an additive for diesel engines is limited to a maximum fraction (typically 15%) because the diesel or primary fuel injection timing is so advanced that knock would be caused at these higher concentrations by the
30 secondary fuel itself.

There are various challenges and problems involved in creating a practical secondary fuelling system capable of providing worthwhile fuel efficiency improvements. These include

- how to optimise the efficiency gains provided by dual fuelling
- 5 - provision of a practical means of controlling the quantity of secondary fuel supplied to the engine
- in a retro-fit secondary fuelling system, controlling the level of secondary fuelling suitably to permit the engine's controller to adjust its own performance in a manner which provides efficiency gains
- 10 - provision of a practical means of monitoring engine performance as a basis for control of secondary fuelling in a retro-fit secondary fuelling system, without digital communication with the engine controller.

Solution or alleviation of one or more problems associated with secondary fuelling is an object of the present invention.

- 15 In accordance with a first aspect of the present invention there is a secondary fuelling system for fitting to an internal combustion engine, the internal combustion engine being configured to be fuelled with a primary fuel and the secondary fuelling system being configured to supply a controlled quantity of a secondary fuel, in addition to the primary fuel, to a combustion
- 20 chamber of the engine, the secondary fuelling system being configured to determine an engine parameter indicative of quantity of primary fuel supplied to the combustion chamber, to calculate a required quantity of secondary fuel to be supplied to the combustion chamber as a function of the monitored engine parameter, and to supply the required quantity of secondary fuel to the
- 25 engine, characterised in that for at least part of the time the secondary fuelling system carries out the determination of the engine parameter and the calculation of the required quantity of secondary fuel during each engine cycle, in that the required quantity of secondary fuel determined in one engine cycle

is supplied to the combustion chamber in the same engine cycle or in the following engine cycle.

The system may be implemented by means of microprocessor technology. It may be implemented using analogue circuitry. The calculation
5 of the required quantity of the secondary fuel may accordingly be implemented using analogue electronics.

Other aspects of the invention are set out in the appended claims.

Preferred embodiments of the invention shall now be described, by way of example only, with reference to the accompanying drawings in which:

10 Figure 1 is a graph representing an envelope for quantity of secondary fuel supplied to the engine in accordance with an aspect of the present invention;

Figure 2 is a graph showing variation of the quantity of secondary fuel supplied to the engine at three different fuelling levels in accordance with
15 an aspect of the present invention;

Figure 3 is a further graph representing an envelope for quantity of secondary fuel supplied to the engine in accordance with an aspect of the present invention;

Figure 4 is a further graph showing variation of the quantity of secondary
20 fuel supplied to the engine at three different fuelling levels in accordance with an aspect of the invention;

Figure 5 is a graph of a Pulse Width Modulated (PWM) primary injector signal;

Figure 6 is a schematic circuit diagram for an injector signal conditioner
25 according to the present invention;

Figure 7 is a graph of an injector signal after signal conditioning according to the present invention;

Figure 8 is a graph showing (a) a conditioned PWM injector signal and (b) an output of a digital potentiometer in an embodiment of the present invention, the PWM signal having a 3ms "on" time;

Figure 9 is a graph showing (a) a conditioned PWM injector signal and (b) an output of a digital potentiometer in an embodiment of the present invention, the PWM signal having a 4.5ms "on" time;

Figure 10 is a schematic of an electronic circuit forming part of an embodiment of the present invention for making a single cylinder engine injector 'on' period measurement;

Figure 11 is an example timing diagram according to an aspect of the present invention for twin or multi cylinder engines;

Figure 12 is a schematic of an electronic circuit forming part of an embodiment of the invention for twin or multi cylinder engine injector 'on' period measurement;

Figure 13 represents a four stage differential amplifier circuit forming part of an embodiment of the invention which combines the injector 'on' period signal with a fuel pressure signal;

Figure 14 is an example timing diagram using two digital potentiometers to provide the gas injector signals to activate two gas injector solenoids in accordance with an aspect of the invention;

Figure 15 is a schematic of an electronic circuit that provides the gas injector signals to activate two gas injector solenoids in an embodiment of the invention;

Figure 16 is a schematic diagram of an exhaust flow measurement

system embodying an aspect of the invention;

Figure 17 is a graphical of the timing of an exhaust pressure signal in an embodiment of the invention;

Figure 18 is a schematic diagram of an engine intake incorporating, in accordance with an aspect of the present invention, a Proportional Gas Valve for secondary fuel injection; and

Figure 19 is a schematic of an electronic circuit for a microprocessor controlled Proportional Gas Valve injection system in an embodiment of the invention.

Figures 1 to 4 relate to the manner in which quantity of secondary fuel varies as a function of quantity of primary fuel supplied to the engine, in certain embodiments of the present invention.

Figure 1 defines an envelope 1 for secondary fuel injection for engines that are slow speed (RPM) and high torque as used typically in heavy goods vehicles (HGV) busses/coaches and rail. The X axis is the mass of primary fuel expressed as a percentage of full load. The Y axis is the percentage of secondary fuel injected as a percentage of the primary fuel. The minimum edge 2 [Minimum Fraction] of the envelope is where significant improvement of combustion begins, typically at 3% by mass secondary fuel injection for secondary fuel in the form of LPG. The maximum edge 3 [Maximum Fraction] of the envelope, typically 15% by mass, is where the inefficiency of combusting a secondary fuel (for an engine designed to combust primary fuel) significantly counters the 'Atkinson cycle' effect (the efficiency gain due to advance of ignition timing made possible by secondary fuelling) therefore resulting in no gain in the overall combustion efficiency. Point 10 represents the fuel flows at engine idle speed. At higher engine loads to the right of line 4 the secondary fuel percentage is reduced because (i) there is less oxygen available and (ii) the engine is required to perform within the design engine load limits for the high load conditions. For example, Figure 1 shows a

decrease in percentage mass secondary fuel injection beyond 60% load of the engine, i.e. the 15% profile 3 is reduced to 13.8% at point 5, 9.4% at point 6, 6.7% at point 7 and 4.75% at point 8. For engines where there is no excess air available at full load then the profile for the amount of gas injected is
5 reduced to zero.

The three lines in Figure 2 represent actual fuelling profiles. In each case the quantity of secondary fuel is substantially proportional to the quantity of the primary fuel in a low load region, up to approximately 60-80% of maximum fuelling. The three lines respectively represent secondary fuelling
10 of 5%, 10% and 15% of primary fuelling, by mass, in this load regime. This level of secondary fuelling is reduced at higher loads for the reasons just discussed. Solid lines 11,12 in Figure 2 show a typical profile where maximum combustion efficiency occurs to produce the minimum of harmful emissions. Profile 11 shows a decreasing percentage injection above 60%
15 of full load (point 4) and profile 12 at 80% load (point 9). The point at which the decrease begins is determined by the duty cycle of the engine; in practice, for example in a heavy good vehicle (HGV), this would be typically set at just above the engine load for a cruising fully laden vehicle. Dashed line 13 and dotted line 14 are the 15% and 5% secondary fuel injection
20 percentages respectively.

Figure 3 defines a suitable envelope 15 for secondary fuel injection for smaller diesel engines that are used typically in modern motor cars and vans. The injection system for these engines offers more control for the primary fuel delivery and uses 'multiburst' (separate rapid firing of injectors)
25 combined with a greater range for the common rail injection pressure. Thus the secondary fuel percentage 16,17 is made proportional to the primary fuel mass over the full load range of the engine. The solid line 18 in Figure 4 shows a more typical profile where maximum combustion efficiency occurs to produce the minimum of harmful emissions. The optimum secondary fuel
30 percentage depends on the engine design - bore/stroke, shape of piston/cylinder head, valve configuration, aspiration system, fuel grade,

engine load and speed. For low engine loads a higher percentage of secondary fuel 10,19 is used for further fuel cost savings without detriment in engine emissions, for example when the engine is at idle or under part-load such as when 'power take off' is used.

- 5 The level of secondary fuelling is limited to a maximum fraction of the diesel or primary fuel beyond which engine knock would begin to occur due to the high concentration of additive or secondary fuel.

In secondary fuelling systems described herein, the amount of secondary fuel to be supplied to an internal combustion engine is determined
10 based on the quantity of the primary fuel being supplied.

The amount of primary fuel injected is a function of the fuel pressure and the time for which a primary fuel injector is open or injecting:

$$Flow = Time \times \sqrt{Pressure}$$

For engines where the fuel pressure is fixed, for example by a constant
15 pressure fuel pump or by a mechanical arrangement such as a cam acting on a spring pressurizing an injector reservoir, the fuel flow rate is directly proportional to the injector open time.

For engines where the fuel pressure is varied, such as in common rail injection systems, the fuel flow is primarily governed by the fuel pressure
20 where the injector is operating at optimum timing. As the engine load is increased or decreased the fuel pressure from the pump does not respond instantaneously so the difference or error is compensated by varying the open time of the injector by the ECU; i.e. the injector open time varies as the load is changed and then returns to the optimum timing. Therefore to calculate fuel
25 flow which responds to changes in engine load both the injector open time and the fuel pressure need to be measured.

The use of multiple injection events has been adopted by many

manufacturers of common rail engines and as a consequence the fuel injection events are considerably shorter than was the case with engines equipped with older distributor pump technology. Thus it has become problematic, in a retro-fit secondary fuelling system, to use a digital processor (microprocessor) with sufficient processing capacity to be used as a second ECU in order to be able to intercept the injector signal and process this signal in real time.

Certain embodiments of the invention to be described below comprise an Injection Control Unit (ICU) which measures the primary injector 'on' time and primary fuel pressure (if required) and uses an analogue electronic circuit which calculates the primary fuel flow and an electronic circuit to provide signals to actuate secondary gas or liquid additive fuel injector(s) in an appropriate timing pattern. The ICU will work on most electronically controlled fuel injected engines. An advantage of this approach is that it accommodates multi-burst firing of the injector control signals.

An alternative embodiment for the ICU system is to replace the diesel engine ECU with a generic petrol engine ECU. The diesel injectors are kept active, initiated from the ICU which uses a 'spark ignition' pulse from the generic engine ECU. Typically the diesel injector pulse from the ICU is between 250 – 320 microseconds. The diesel fuel pressure is maintained at a minimum value. The conventional 'spark plug' is effectively replaced by a minimal amount of diesel injection which auto ignites and starts the combustion of the alternative fuel. Preferably liquid gas injectors are used similar to a petrol direct injection engine, thus no fuel is compressed during a compression stroke. The ICU converts the petrol injector signals generated by the generic petrol ECU to control the liquid gas injectors for the diesel engine.

An alternative approach to determining the quantity of primary fuel injected to the engine is to monitor exhaust gas pressure.

The exhaust gases comprise air and combustion products such as H₂O/CO₂. Other combustion products such as particulate matter

(PM)/NO_x/CO may also be present and are an indication of inefficient combustion. However the total mass of exhaust products is equal to the total mass of input matter (air and fuel). Thus an approximation is made for the amount of diesel injected based on the mass flow of the engine exhaust.

5 Exhaust gas pressure is used as a measure of this mass flow. In order for the ECU to adapt to the secondary engine fuelling, the amount of gas additive needs to be determined for each engine cycle according to a primary fuel flowrate measurement. This is accomplished on a cycle by cycle basis provided that the measurement transducer (e.g. a pressure sensor) has a

10 sufficiently fast response and is situated close to the exhaust ports, preferably on the exhaust manifold of the engine. A pressure transducer is used to provide an exhaust flow measurement using the differential pressure principle across the exhaust system from exhaust manifold to ambient (atmospheric pressure). This peak signal provides the primary fuel flow measurement to

15 calculate the amount of high octane additive fuel to inject for each cycle.

Some engines have factory fitted exhaust pressure sensors whose outputs may be employed for the present purpose. Specifically, in an engine fitted with a diesel particulate filter (DPF) it is possible to use a DPF pressure measurement directly to provide the peak signal from an exhaust cycle of a

20 cylinder. This peak requires measurement before an induction stroke begins as is the case for low speed engines. For high speed engines the pressure transducer must be located closer to the exhaust port to ensure the peak is measured before an induction cycle begins. The peak pressure measurement assumes a constant pneumatic resistance across the exhaust system. The

25 DPF pressure differential builds up over time as the pneumatic resistance increases due to the trapped PMs. The differential DPF signal is subtracted from an absolute exhaust pressure measurement to compensate. A similar compensation is required for systems using Exhaust Gas Re-circulation (EGR), selective reduction catalyst (SCR) or in systems where the turbo

30 charger is fitted with variable vane technology.

Figures 5 – 13 relate to measurement of the injector open or 'on' time.

Figure 5 is an illustration for the voltage across a typical fuel injector when PWM is used to control the current passing through a solenoid injector. The average current is determined by the duty cycle (pulse width) of the signal. Typically the frequency of the PWM is approximately 24 KHz in modern
5 injector driver systems. It is not uncommon to see much higher voltages across an engine fuel injector – negative and positive voltages are observed as high as several hundred volts in part due to the back electromotive force from the solenoid. Initially a high (peak) current is required for a short duration (typically 0.2 – 2 ms as indicated at 20-21 in Figure 5) to ‘crack’ open the
10 injector solenoid and involve high voltages to achieve this. If this current were to be maintained the solenoid would overheat and fail; the PWM technique is used to supply just enough current to ‘hold’ the injector open. The pulsed signal used for this purpose is seen at 22 in Figure 5. It therefore is deduced that the injector is fully open for the ‘hold’ current period 22 and fuel is flowing
15 through the injector until it is closed at 23.

Referring to Figure 6, pulse counting circuitry 200 is provided in this embodiment with multiple electrical connections 202 to the engine’s electrical system. Each comprises a conductor connected to receive the PWM signal applied to a respective primary injector of a multi-cylinder engine. Each is
20 connected to a combination 204 of signal diodes, zener diodes, resistors and capacitors to provide a high impedance input to the circuit from each engine injector. In this way there is minimal interference with the engine injector signals. Any negative voltage and/or high frequency spikes are removed and the positive voltage is limited to just below 5 volts. The injector signals are
25 passed on to a differential amplifier 24. Both common ground and push-pull engine injector signals are accommodated using the differential amplifier 24 which has a single output for each injector. For engine injector signals that use a common ground then one of the differential amplifier inputs for each injector is also grounded. The signal is further cleaned by using a Schmitt trigger gate
30 such as a NAND gate 25 which in Figure 6 is used for two engine injectors providing two outputs 26, 27. Outputs 26, 27 are also used to activate and time the secondary fuel injection. The secondary fuel is only injected when the

primary engine injectors are operating. An additional input 28 is shown which de-activates the secondary fuel injection, for example if there is no secondary fuel available (tank empty). For primary injectors that do not use the PWM technique to control current (such as some solenoid systems and piezo injectors) an additional input 29 is used to provide a pseudo PWM signal at 24 KHz when the injector is 'on'. This pseudo signal would emulate a PWM injector signal including the initial 'peak' period where the injector is opening. In this way the circuit provides outputs for all types of engine fuel injector. Figure 7 shows a typical primary injector signal after signal conditioning.

10 The PWM pulses are applied to the clock input of a digital potentiometer which increments a 'wiper' for every positive or negative edge transition of the engine fuel injector signal. The digital potentiometer effectively counts the number of PWM pulses of the engine injector signal providing an analogue voltage output from the 'wiper'. Figure 8 shows the output 30 of the digital
15 potentiometer wiper for an injector open for 2 ms. In this example the voltage output is 2.1 volts which corresponds to twenty one counts or increments made by the digital potentiometer. Since the frequency of the PWM is constant the number of counts and corresponding output voltage 30 is directly proportional to the hold time of the injector. Figure 9 shows the output 31 of
20 the digital potentiometer wiper for an injector open for 3.5 ms (32). In this example the voltage output is 3.5 volts which corresponds to thirty five counts or increments made by the digital potentiometer. Figures 8 and 9 illustrate the principle of using a digital potentiometer to measure the open time of a fuel injector. In a typical diesel engine the injector open times vary between 0.2 –
25 2.5 msecs and for petrol engines injectors 1 - 25 msecs. A 128 step digital potentiometer providing 0-5 volt output is preferred in the following description of the present invention; however digital potentiometers having a greater number of step increments are used. Thus it is possible to measure the open time of a typical diesel fuel injector to within a few microseconds when a PWM
30 signal is used to drive the injector.

Figure 10 represents a circuit for a single cylinder engine comprising one

fuel injector where a single digital potentiometer 34 is used in conjunction with a sample/hold operational amplifier 35 and pulse generator 36 to provide an analogue voltage proportional to the open time of the fuel injector. The digital potentiometer has an up/down or increment/decrement input 37. It is possible
5 to decrement the wiper output 38 from the maximum value to zero (Figure 8, 39) within the peak current time period as typical clock speeds of modern devices range up to 1 MHz. For example to count down 128 steps using a 1 MHz clock takes 0.128 ms, which is within the peak current time period used by most fuel injectors. When an injector signal 33 arrives a dual monostable
10 36 generates a 'chip select' pulse 40 just larger than the maximum injector signal period including multi-burst firing (typically <15 ms) from the first transition of the injector signal. Dual monostable 36 generates a further up/down pulse 37 which is just smaller than the peak current period of the injector (typically less than 1 ms) from a transition of the 'chip select' signal.
15 The chip select signal 40 is used to set the hold condition of the sample/hold amplifier 35. An electronic switch 41 switches either a high frequency clock (400 KHz – 1 MHz) or the injector signal 33 to the clock input of the digital potentiometer 34 depending on the logic state of the up/down signal 37. Thus on arrival of an injector signal: chip select 40 sets sample/hold 35 to hold,
20 enable digital potentiometer 34, up/down signal 37 set to 'down', switch 34 connects high frequency clock to the clock input 42 of digital potentiometer 34 and therefore the wiper output 38 decrements to zero. After the wiper has 'reset', the up/down signal 37 returns to 'up', switch 34 connects injector signal 33 to clock input 42 of digital potentiometer 34 and the wiper output 38
25 increments according to the number of PWM pulses of the injector signal 33. The 'chip select' signal returns and the sample/hold amplifier 35 then samples and output the new wiper voltage. In this way an accurate measurement of the injector 'open' time is made which automatically takes into account the time taken for the injector to open.

30 Prior art patent GB2488814 discloses a method which measures the current passing across a fuel injector using a Hall Effect current transducer. In this system the total injector 'on' period is measured including the peak current

period and the resultant error would accumulate during a multi-burst injection event. The current sensor requires a calibration time in order to 'lock' onto the injector signal and is not immune to stray magnetic field interference. The present invention offers significant advantages because voltage across the injector is measured and thus provides an interference free measurement of the injector 'open' time. The method automatically takes into account the time taken for the injector to open and thus provides a better measurement (particularly for multi-burst injection events) of fuel flow almost instantaneously; i.e. the ICU provides a measurement as soon as it is switched on and an engine injector signal is immediately processed.

For multi – cylinder engines the sample/hold amplifier is not required since a previous injection signal output is used until the current injection measurement has completed. Figure 11 is an example timing diagram where two digital potentiometers are used with two injector signals 43, 44. A monostable outputs 'chip select' signals 45, 46 on the first +ve edge transition of the injector signals 43, 44. A further monostable outputs 'up/down' signals 47, 48 on the +ve transition of chip select signals 45, 46. Up/down signal 47 is used to enable an electronic switch to connect a high frequency clock input to a first digital potentiometer to down-count 49 and on disable connect the injector PWM signal to up-count for the injector 'on' period 50. The –ve transition of chip select signal 45 is used to connect the output voltage V1 of a first digital potentiometer via setting of a D-Type flip-flop (51) using pulse 52 which enables the output V1 to be switched to output signal 53. Similarly the –ve transition of chip select signal 46 is used to connect the output voltage V2 of a second digital potentiometer via re-setting of a D-Type flip-flop 51 which enables the output V2 to be switched to provide an updated output signal 53. In this example the injector 'on' period is reduced over four periods 50, 54, 55 and 56 resulting in the corresponding output voltage 53 to reduce outputs V1, V2, V3 and V4.

Figure 12 is an embodiment of an electronic circuit that realises the timing diagram of Figure 11. Dual monostables 57, 58 output 'chip select' 45,

46 and up/down 47,48 signals for the digital potentiometers 59, 60. Electronic switch 61 either connects the injector PWM signals 43, 44 or the high frequency 'down-count' signal 62 which in this embodiment is generated by an astable timer 63. A D-type flip-flop 64 and NAND function logic gates 65
 5 provide the enable signals for electronic switch 66 to select the appropriate digital potentiometer output signal 49, 50 to output 53. The function of resistor 67 and capacitor 68 is to remove high frequency noise and 'smooth' the output signal 53.

This arrangement is used for two cylinder engines and is sufficient for
 10 additive injection in four cylinder engines. In a four cylinder engine the injector signals used are chambers 1/3 or chambers 2/4 or when the two injector signals are equally phased apart. Similarly three 3 injector signals are used for straight six engines, four for 'V6/V8 engines. However for sequential injection systems and where a fast update time is required a measurement is
 15 made from each injector for every chamber.

Where the fuel pressure is not constant (for example in a common rail engine) signal 53 representing the injector 'on' period is combined with a 'fuel pressure' signal to determine the fuel flow. This signal is available on engines which vary the fuel pressure in order to control the amount of fuel delivered.
 20 Typically the pressure transducer would have a separate ground, regulated voltage supply (5 volts) and output a signal that varies between 0.5 – 4.75 volts. For pressure transducers typically used in the automotive industry the output voltage is not linearly proportional to the fuel pressure. Since it is not possible to vary the fuel pressure instantaneously, the injector 'on' period is
 25 also adjusted in order to control the amount of fuel delivered as the engine is accelerated/decelerated. The injector 'on' timing is optimised for efficient operation of the engine and therefore a change in this timing represents an 'error' caused by the 'lag' when adjusting the fuel pressure according to engine load demand. Thus the fuel flow is approximated by:

$$30 \quad \text{Flow} = Gi(I_{on} + O_i) \times Gp(P + O_p)$$

Where:

Flow = fuel flowrate

Ion = Injector 'on' period signal

Gi = Gain applied to Injector 'on' signal

5 *Oi* = Offset applied to Injector 'on' period signal

P = Fuel Pressure signal

Gp = Gain applied to fuel pressure signal

Op = Offset applied to fuel pressure signal

10 Ideally the above equation the term $Gi(Ion + Oi)$ has a unity value when the injection timing is optimised and the fuel pressure has stabilised according to engine load. By careful selection of offset and gain the fuel pressure signal sufficiently approximates the fuel flowrate for an injector with a fixed 'on' period within the operational limits (figures 1 – 4) of the gas injection system. Thus the fuel flow is further approximated by:

15
$$Flow = Gain(Gi(Ion + Oi) + Gp(P + Op)) + Offset$$

20 In the above equation the term $Gi(Ion + Oi)$ has a zero value when the injection timing is optimised and the fuel pressure has stabilised according to engine load. A further *Gain* and *Offset* are applied to the combined signal to improve the approximation. Both of the above equations are realised using electronic components such as a multiplier amplifier or summing operational amplifier.

25 Figure 13 shows an embodiment of a four stage differential amplifier circuit which combines the injector 'on' signal 53 with the fuel pressure signal 69, 70. A unity buffer amplifier 71 combines the pressure transducer signal ground 70 with an offset adjustment 72 using a summing amplifier 73 and the resulting signal passed to the first stage 74 of differential amplifier 74, 75, 76. Unity gain buffer amplifiers 77, 78 feed fuel pressure signal 69 and injector 'on' signal 52 to a resistor network where the gain ratio is adjusted 79 before summing by amplifier 80. The output of the summing amplifier 80 is passed to 30 the first stage 75 of differential amplifier 74, 75, 76. The overall gain of the

combined signals are adjusted 81 for the differential amplifier 76 which outputs a signal 82 representing the fuel flow of the injector. In this way for engines where there is no fuel pressure signal the input 69 is grounded and only the injector 'on' signal 53 processed by the amplifier.

5 Figure 14 is an example timing diagram where two digital potentiometers are used with two injector signals 43, 44 to activate two gas injector solenoids. Here an alternative circuit is disclosed for measuring the injector 'on' period whereby a minimum of circuit components are used and where the peak current period for the gas injectors is adjusted for different models of secondary fuel injector. A monostable outputs 'chip select' signals 45, 46 on
10 the first transition edge of the injector signals 43, 44. A further monostable outputs 'up/down' signals 83, 84 on a transition edge of chip select signals 45, 46. The signals 83, 84 are used to enable an electronic switch to either connect a high frequency clock input to digital potentiometers to down-count
15 or connect the injector PWM signal to up-count for the injector 'on' period. The -ve transition of chip select signal 45 is used to connect the output voltage V1 of a first digital potentiometer via setting of a D-Type flip-flop 51 which enables the output V1 to be switched to output signal 53. Similarly the -ve transition of chip select signal 46 is used to connect the output voltage V2 of a second
20 digital potentiometer via re-setting of the D-Type flip-flop 51 which enables the output V2 to be switched to output signal 53. In this example the injector 'on' period is reduced over four periods resulting in the corresponding output voltage 53 to reduce V1, V2, V3 and V4. This signal is combined with the fuel pressure signal if required as described above (Figure 13) and is used as the
25 reference signal 82 in order to determine the gas injector 'on' times T1, T2, T3 and T4. Alternatively microprocessor could be used to count the PWM pulses to provide a diesel injector 'on' period albeit not 'instantaneously' as in the circuit described above.

 Further monostables output 'up/down' signals 87, 88 for the gas injector
30 digital potentiometers. In this embodiment the trigger for these signals is taken from the +ve edge transition of 'chip select' signals 45, 46 and in doing so the

gas injectors will operate simultaneously with the engine injector firing. Whilst this is not a problem for most diesel engines, with petrol engines which utilise an 'Atkinson' cycle effect by varying the valve timing and phase during an engine cycle it is required to adjust the secondary fuel injection timing. The

5 secondary fuel is injected as close to the inlet valve(s) as possible using an injector for each cylinder, herein referred to as sequential timed secondary fuel (gas, or gas in liquid phase) injection. Ideally the secondary fuel is injected when the inlet valve is open and the exhaust valve is closed. This result in a delay after the inlet valve is first opened during the induction stroke, until the

10 exhaust valve is closed; at which point the secondary fuel is injected without passing directly into the exhaust. Thus the secondary fuel injection cycle begins on an induction stroke where the inlet valve(s) is open and the exhaust valve(s) is closed and ends when both inlet and exhaust valves are closed. Incorrect secondary fuel injection timing is a major cause of engine

15 malfunction and inefficient combustion for LPG converted petrol engines because the secondary fuel injectors cannot occupy the same position in the inlet manifold as the petrol injectors and therefore require different timing to the petrol injectors. Thus it is required that the secondary fuel injection needs to be advanced or delayed for correct operation in a sequential system, and

20 therefore other crankshaft position/velocity sensors are used to trigger signals 87 and 88 to achieve this. Where a non-sequential system is used (as in conventional, non-'Atkinson' cycle effect diesel engines) the secondary fuel freely flows through the intake manifold and the secondary fuel is injected asynchronously to the engine. In this instance the trigger for the secondary

25 fuel injectors for example is obtained from an astable running at an appropriate frequency; provided that there is always additive injected in the correct ratio for each induction stroke of the engine.

In this embodiment the period of signals 87, 88 is set to ensure the opening of the secondary fuel injector. The secondary fuel is a gas, although

30 it could alternatively be a liquid fuel. The peak current time for a gas injector to open typically ranges from 1 – 3 ms. Signals 87, 88 are used to set a D-type Flip-Flop 89, and used as the 'up/down' input which resets a secondary

fuel timing digital potentiometer by connecting a high frequency clock input which thus counts down or decrements the output to zero as at 90 in Figure 14. The digital potentiometer is then set to increment using clock signals from an adjustable astable in the range 1 – 5 KHz (91). A comparator operational
5 amplifier is used to compare the output voltage from the digital potentiometer with the reference signal representing the fuel flow 82. When these signals D1, D2, D3 and D4 are equal the comparator output changes and this transition resets the D-type flip-flop 92. Thus digital potentiometer signals 93, 95 and D-type Flip-Flop output 94, 96 represent the secondary fuel injector
10 'on' periods according to the measured fuel flowrate signal 82. In this example the secondary fuel injector 'on' period is reduced according the reducing fuel flow measurements D1, D2, D3 and D4 and corresponding secondary fuel injector 'on' time T1, T2, T3 and T4 for two secondary fuel injector outputs 97, 98. The secondary fuel injector outputs 97, 98 comprise an adjustable
15 'peak' current time 87, 88 and a 24 KHz PWM signal where the duty cycle is also adjustable to provide an average current rating to maintain the open state of the secondary fuel injector.

Figure 15 is an embodiment of an electronic circuit that realises the timing diagram of Figure 14 where inputs 99, 100 are the triggers for two
20 secondary fuel injectors. These signals are either be taken from +ve or –ve edge transition of 'chip select' signals 45, 46 or other crankshaft position/velocity sensors that provide an injector timing sequence for example when an advance/retard is required for the secondary fuel injectors. Monostable 101 outputs the secondary fuel injector 'peak' pulses 102, 103
25 which are also used as up/down signals for the digital potentiometers 104, 105 and as enable inputs for an electronic switch 106 which either connects a high frequency 'down-count' signal 107 or the adjustable 'up count' signal 108 to the clock inputs of digital potentiometers 104, 105. In this embodiment the 'up count, 'down count' and adjustable secondary fuel injector PWM signals are
30 generated by astable timers 109, 110. On arrival of an engine firing pulse 99 monostable 101 generates a peak secondary fuel injector pulse 102 and the secondary fuel injector begins to open and during this peak current period the

digital potentiometer decrements to zero. A D-type flip-flop 111 is 'set' and enables the peak signal to pass through NAND function logic gate 112 boosted through driver 113 and activate the secondary fuel injector MOSFET 114. When the secondary fuel injector has opened and the peak pulse period
5 completed the NAND gate then allows a 24 KHz signal to pass in order to maintain the 'hold' condition for the secondary fuel injector. The digital potentiometer 104 is incremented using the 'up count' signal and comparator 115 compares the digital potentiometer output to the input fuel flowrate signal 82. When this output voltage is equal to the fuel flowrate signal 82 the output
10 of the comparator 115 changes state causing the D-Type flip-flop 104 to reset and thus the secondary fuel injector is switched off as at 112, 113. On arrival of an engine firing pulse 100 an identical process using a monostable 101, D-type flip-flop 111, digital potentiometer 105, electronic switch 106, astable timers 109, 110, comparator 115, NAND gate 112 and driver 113 is used to
15 activate a second secondary fuel injector. A variable resistor 117 is used to adjust the duty cycle of the PWM hold current to allow different specification secondary fuel injectors to be used. Variable resistor 118 is used to control the 'on' period of the secondary fuel injector for a given fuel flowrate 82 signal. The amount of secondary fuel delivered is thus a function of the gas pressure
20 and resistor 118 value. Alternatively a microprocessor could be used to process the secondary fuel injector firing signals and provide a secondary fuel injector 'on' period albeit not 'instantaneously' as in the circuit described above.

Figure 16 is an embodiment of a system whereby the cycle by cycle
25 measurement of fuel flow is made by measuring the exhaust pressure. Combustion products enter exhaust manifold 119 to the exhaust 120, pass pressure sensor 121, turbocharger 122, oxidation catalyst 123, diesel particulate filter ("DPF") 124, selective catalytic reduction 125 and finally exit
30 from silencer 126 where these components are fitted. The DPF filter having two pressure transducers 127, 128 are used to provide a differential signal across the DPF, used by the ECU to determine DPF purge. Pressure sensor 121 is best positioned pre – turbo if fitted to obtain a signal which better

correlates to exhaust mass flow and hence provide a fuel flow measurement.

The engine speed (RPM) is determined by a timer measurement using the diesel injector actuation signals from the ECU. A more precise measurement is made using several injection pulse timing measurements from each cylinder. Thus it is possible to determine the crank angle by using a timer initiated on an injection pulse and the time an exhaust valve opens is determined. As soon as the exhaust valve is opened a pressure wave travels through manifold 119 into exhaust pipe 120 and arrives at pressure sensor 121. This time interval is fixed and depends on the distance of pressure sensor 121 from the exhaust valve. A timer value which varies as a function of RPM is therefore calculated which is used to start the ADC sampling of the exhaust pressure sensor 121.

Figure 17 shows a graphical representation of the exhaust pressure signal 129. After an injection pulse 130, 131 has been detected the sampling begins after crank angle 132 which is calculated using engine speed and loaded into a timer as a time interval. The exhaust pressure is sampled for timed window 133. During the window the ADC values are stored. These values are processed digitally to remove spikes. A stacked average method could be used whereby when a new value is added to a stack, the last stack value discarded, the stack is then averaged to give a new stack average; this value is stored. When the window has completed the stored stack averages are compared and a peak value for the window obtained. The process is repeated for each diesel injection thus obtaining a peak value of exhaust pressure for each engine cycle. The magnitude of this pressure signal relates to the amount of primary fuel combusted and provides a signal that is used to determine the amount of high octane fuel added for each engine cycle.

Figure 18 shows an embodiment of the invention whereby the secondary fuel injectors described above are replaced with a single proportional valve. This application requires a fast response proportional valve that actuates within a few milliseconds. The engine air intake passes through air filter 135

and is compressed or 'charged' by charger 137 before entering the engine intake manifold. A proportional gas valve 138 is used to inject a flow of secondary fuel in the form of gas through nozzle 139 controlled using an electrical input 140. Typically this electrical input uses PWM current regulation to control the valve. The gaseous fuel 141 enters filter 142 at a regulated pressure measured by pressure sensor 142 and temperature measured by sensor 143. In this way temperature/pressure corrections are made to ensure the correct amount of secondary fuel is injected. An advantage of using a proportional valve is that a continuous amount of secondary fuel is delivered rather than being injected as pulses. In this preferred embodiment the secondary fuel valve is positioned close to the engine intake manifold downstream of an engine turbocharger.

Figure 19 is a schematic circuit diagram of the secondary fuel additive injection system using a proportional gas valve. A diesel injector signal 144 is signal conditioned at 145, 146 and input to processor 147. One, several or all the engine diesel injectors may be used for inputs, however not all the diesel injector inputs are necessary as other injector inputs are simulated by the processor. For example several measurements are made from a single injector to determine if the engine is accelerating or decelerating and therefore a predictive technique used to simulate the firing other injectors. The injector on time and common rail diesel fuel pressure 148 are measured and engine speed (RPM) is calculated to determine the primary fuel flowrate. The secondary fuel pressure 149 and secondary fuel temperature 150 are measured and the secondary fuel flow rate calculated as a proportion of primary fuel flow. The secondary fuel flowrate output signal 151 is a PWM signal used to actuate proportional secondary fuel valve (Figure 18, 138) through driver 152.

This circuit requires minimal modification to use the exhaust method described above to calculate a primary fuel flow measurement. A diesel injector signal 144 is used to calculate the engine speed and exhaust gas pressure (Figure 16, 121) and to measure timings (Figure 17, 132 and 133).

The exhaust gas pressure measurement now replaces the common rail input 148 signal and the processor determines a primary fuel flow measurement using the exhaust gas measurements. The gas valve is actuated as described above.

5 In this embodiment a tank fuel level signal 154, signal conditioned through amplifier 155 and input to processor 147 is shown. Processor 147 is used to output on a display 156 the operation of the gas injection system for the driver of the vehicle. Such display parameters include the fuel level, engine speed, injector firing, instantaneous fuel flow, secondary fuel
10 pressure/temperature, fuel flow. The display may also have a control input to adjust the ratio of injected secondary fuel/injected diesel.

 In this way the control function of an engine management system (EMS) is not affected and remains in full control of the engine; there are no software modifications required for the EMS, a modern EMS will adapt to the new
15 engine fuelling automatically. For example, for engines fitted with a 'knock' sensor the EMS advances the injection timing for the new fuelling because of the improved RON of the dual fuel. However, since the required signal data is hardwired within the ECU, the control of the secondary fuel injection may advantageously be managed by the ECU itself. This is often difficult to achieve
20 in a retro-fit secondary fuelling system, however.

 Power to the secondary fuel injection system is via a fuse from the ignition circuit; in the event of a vehicle incident (for example if the air bags inflate) this circuit is immobilised and the secondary fuel system shut down.

 The diesel injector signal is primarily used to determine when the
25 secondary fuel injectors are active, for example when a vehicle is decelerating or going downhill, when there is no load demand, the EMS de-activates the diesel injectors to conserve fuel. In that case the secondary fuel injectors are also de-activated; i.e. secondary fuel is only injected when primary fuel is injected.

The circuit is powered from the vehicle battery via the ignition circuit and protected with fuse. For vehicles without automatic emergency engine shut off it is preferable to interface the secondary fuel supply control to the electronic circuit to enable an automatic secondary fuel shut off in the event where the engine is not running for a period of time. In this event the relays for the secondary fuel tank solenoid and vaporiser solenoid is de-activated; hence secondary fuel is supplied when the engine runs in normal conditions and is shut off in an emergency automatically.

This example is used for secondary fuel injection at the air intake for engines where there is no valve timing overlap between exhaust stroke and induction stroke of the piston; i.e. the exhaust valve is closed as the intake valve is opened. At least two or more injectors are required to ensure consistent secondary fuel delivery during the induction stroke and preferably the secondary fuel injection period at least twice the period for a piston stroke for each injector. Typically the injection period will be in the range 3 - 80 ms. A single gas injector may be used providing there are at least sufficient injection periods within a stroke of the piston in order to deliver consistent quantities of secondary fuel for each engine cycle. However a single injector system would have a shorter working life and for high speed engines the short injection period required will cause non-linearity of secondary fuel delivery due to 'water hammer' effect. The circuit is also used for liquid injection systems and high pressure secondary fuel injection systems where the injection occurs at a precise time during the induction and/or compression stroke and correspondingly involve shorter secondary fuel injection periods. Given that the injection time of the primary fuel is shorter than the injection time of the secondary fuel it is possible to determine the current flowrate and the second additive fuel or alternative fuel supplied to the combustion chamber during the same combustion cycle using the current primary injector signal in real time.

A 10 volt regulator is used to supply the preferred voltage for the MOSFET driver 113. The secondary fuel injection signals may be displayed

using LED's and a further LED used to indicate correct operation of the secondary fuel injection system via a 'watchdog' circuit and may be used to signal 'trouble' codes such as for example, 'low secondary fuel pressure'. In this event the secondary fuel injectors are automatically switched off. Ten
5 segment bar LED's may be also used to indicate secondary fuel tank level and also provide an instantaneous fuel flowrate display for the operator.

Typical results on a diesel engine are considered to provide a reduction in primary fuel consumption of around 10 - 25%, using only 3 - 12% of additive high octane fuel to achieve this improvement. Emission reductions are
10 typically 40% to 70% reduction in nitrogen oxides, 80% to 98% reduction in smoke and particulate matter, and a reduction of carbon dioxide and other emissions reflective of the reduction of overall fuel used and the improved efficiency of the engine. Similarly for petrol engines the high octane secondary fuel improves combustion. These improvements are achieved in a non-
15 invasive manner so that the engine life and/or periods between servicing will be extended due to improved combustion and reduction in carbon deposits.

The present invention also offers a low cost solution for the conversion of diesel or petrol injection engines to be converted to run on lower cost fuels such as LPG or green fuels such as methane or bio-gas.

20 Suitable secondary fuels for use in embodiments of the present invention include, but are not limited to: liquefied petroleum gas (LPG), natural gas in CNG or LNG form, Browns Gas, methane, methanol, ethanol, hydrogen and petrol (gasoline), and may comprise two or more different fuels of different molecular structures. In particular, although embodiments described herein
25 relate to gas injection of the additive fuel, a liquid injection system may also be used.

A common property for the short chained molecules including hydrogen is that they have a high Research Octane Number. The octane number of the secondary fuel is higher than that of the primary fuel. Thus for example petrol
30 (gasoline) is used as a secondary fuel in a diesel engine. Although hydrogen

(RON > 130) does not fit well into the normal definitions of octane number, it has low knock resistance in practice due to its low ignition energy (primarily due to its low dissociation energy) and extremely high flame speed. However, as a secondary fuel hydrogen raises overall knock resistance as do
5 the other secondary fuels for example; methane (RON 120), methanol/ethanol (RON 109), ethane (RON 108), propane/butane (RON 112). The anti-knock properties of the combined fuel are increased. The higher the octane number of the combined fuel, the more compression this fuel withstands before detonating. Accordingly, the engine efficiency is improved because fuels with
10 a higher octane rating are used in high-compression Otto cycle engines that generally have better performance both in terms of power and economy.

The anti-knock properties of the secondary fuel allow the engine to advance the injection timing which gives more time to combust the long chain molecules of the primary lower octane fuel. This results in a reduction in fuel
15 consumption while at the same time improving the emissions standard of the engine. This adjustment of the engine is also facilitated by the cycle-by-cycle adjustment of the quantity of the secondary fuel supplied.

For Otto cycle engines equipped with a knock sensor the ECU will retard the ignition timing when detonation is detected. Retarding the ignition timing
20 reduces the tendency of the fuel-air mixture to detonate, but also reduces power output and fuel efficiency because the power stroke is effectively shortened. However the anti-knock properties of the combined fuel are increased which allows the ignition timing to be further advanced thus allowing more time for combustion and effectively extending the power stroke (Atkinson
25 cycle). Accordingly, the engine efficiency is improved because when fuels with a higher octane rating are used the ignition timing is further advanced providing better performance both in terms of power and fuel economy.

Diesel has a very low octane (RON 20) and is more typically described by the Cetane number which reflects the fuels ability to auto-ignite. A diesel
30 engine uses a high compression ratio to allow auto-ignition of the diesel fuel

and is therefore not designed to combust lighter LPG or other small molecule fuels alone. For Diesel cycle engines equipped with a knock sensor the ECU will retard the diesel injection timing when detonation is detected. The anti-knock properties of the combined fuel are significantly increased by the
5 secondary fuelling and allow the injection timing to be advanced thus allowing more time for combustion and effectively extending the power stroke (Atkinson cycle).

CLAIMS

1. A secondary fuelling system for fitting to an internal combustion engine, the internal combustion engine being configured to be fuelled with a primary fuel and the secondary fuelling system being configured to supply a controlled quantity of a secondary fuel, in addition to the primary fuel, to a combustion chamber of the engine, the secondary fuelling system being configured to determine an engine parameter indicative of quantity of primary fuel supplied to the combustion chamber, to calculate a required quantity of secondary fuel to be supplied to the combustion chamber as a function of the monitored engine parameter, and to supply the required quantity of secondary fuel to the engine, characterised in that for at least part of the time the secondary fuelling system carries out the determination of the engine parameter and the calculation of the required quantity of secondary fuel during each engine cycle and in that the required quantity of secondary fuel determined in one engine cycle is supplied to the combustion chamber in the same engine cycle or in the following engine cycle.
2. A secondary fuelling system as claimed in claim 1 in which the required quantity of fuel determined in an engine cycle is supplied to the combustion chamber in the same engine cycle.
3. A secondary fuelling system as claimed in claim 1 or claim 2 in which the monitored engine parameter is open time of a primary fuel injector of the engine.
4. A secondary fuelling system as claimed in claim 3 which is configured to count pulses in a pulsed signal applied to the primary fuel injector in order to establish its open time.
5. A secondary fuelling system as claimed in claim 4 comprising an electronic controller configured to be electrically connected to the primary fuel injector in order to monitor its open time.

6. A secondary fuelling system as claimed in claim 5 comprising a high impedance path through which the controller is connectable to the primary fuel injector.
7. A secondary fuelling system as claimed in claim 6 in which the high impedance path incorporates a filter to remove high frequency spikes.
8. A secondary fuelling system as claimed in claim 6 or claim 7 in which the high impedance path incorporates a voltage limiting element to limit voltage applied to the controller.
9. A secondary fuelling system as claimed in any of claims 6 to 8 in which the high impedance path leads to a logic gate to provide a square wave signal.
10. A secondary fuelling system as claimed in any of claims 4 to 9 further comprising a digital potentiometer configured to supply a first analogue signal representative of number of pulses applied to the primary fuel injector during an injection event.
11. A secondary fuelling system as claimed in claim 10 in which the controller further comprises a high frequency clock selectively connectable to the digital potentiometer to decrement its output to zero between injection events.
12. A secondary fuelling system as claimed in claim 10 or claim 11 further comprising supply control circuitry for controlling opening of a secondary fuel supply device, the supply control circuitry comprising a timing circuit which outputs a second analogue signal proportional to open time of the secondary fuel supply device during a secondary fuel supply event and a comparator configured to compare the first analogue signal to the second analogue signal and to cause closure of the secondary fuel supply device in response to that comparison.
13. A secondary fuelling system as claimed in any of claims 1 to 12 configured to supply the secondary fuel to the combustion chamber concurrently with injection of the primary fuel to the combustion chamber.

14. A secondary fuelling system as claimed in any preceding claim configured to respond to multiple injection events in a single engine cycle, calculating in respect of each injection event a required quantity of secondary fuel and opening and closing a secondary fuel supply device more than once during a single engine cycle to supply the required quantity of secondary fuel.

15. A secondary fuelling system as claimed in any of claims 1 to 14 configured to initiate supply of the secondary fuel upon opening of a primary fuel injector of the engine, and to continue supply of the secondary fuel until the required quantity of secondary fuel has been delivered.

16. A secondary fuelling system as claimed in claim 14 or claim 15 in which the rate of supply of secondary fuel is such that in any given injection event supply of the primary fuel ceases before the corresponding required quantity of secondary fuel has been delivered.

17. A secondary fuelling system as claimed in any preceding claim in which determination of the required quantity of secondary fuel is based upon open time of a primary fuel injector and upon fuel pressure applied to the primary fuel injector.

18. A secondary fuelling system as claimed in claim 1 or claim 2 in which the monitored engine parameter is exhaust gas pressure.

19. A secondary fuelling system as claimed in claim 18 in which sampling from an exhaust gas pressure sensor is coordinated with engine crank position whereby sampling is carried out during passage of a pressure wave through an exhaust of the engine.

20. A secondary fuelling system as claimed in claim 19 in which sampling is carried out over a predetermined time period which commences when the engine crank is at a predetermined angular position.

21. A secondary fuelling system as claimed in claim 20 in which exhaust pressure values obtained during the predetermined time period are processed to provide a value indicative of the quantity of the primary fuel supplied in a single combustion cycle.

22. A secondary fuelling system as claimed in claim 21 in which said processing comprises one or more of (a) low pass filtering; (b) averaging; and (c) obtaining a peak value.

23. A secondary fuelling system as claimed in any of claims 19 to 22 in which timing of signals to at least one primary fuel injector of the engine is measured as an indicator of engine crank position.

24. A secondary fuelling system as claimed in any of claims 18 to 23 which is configured to receive a signal from at least one filter pressure sensor associated with a particulate filter in the engine's exhaust.

25. A secondary fuelling system as claimed in claim 24 which comprises a further pressure sensor mountable in the exhaust, and in which a signal from the further pressure sensor is modified based on the signal from the filter pressure sensor, to compensate for changes in flow resistance in the exhaust that take place over time.

26. A secondary fuelling system as claimed in any of claims 18 to 25 which further comprises a pressure sensor for mounting to the engine's exhaust manifold.

27. A secondary fuelling system as claimed in any of claims 1 to 26 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber takes place during the engine's induction stroke whilst an engine inlet valve associated with the combustion chamber is open and an engine exhaust valve associated with the combustion chamber is closed.

28. A secondary fuelling system as claimed in claim 27 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber ends whilst the engine inlet valve and the engine outlet valve are both closed.

29. A secondary fuelling system as claimed in any of claims 1 to 26 in which supply of secondary fuel is coordinated with injection of primary fuel to the combustion chamber but is retarded or advanced relative to it.

30. A secondary fuelling system as claimed in any preceding claim in which the required quantity of secondary fuel increases monotonically with quantity of the primary fuel injected to the combustion chamber, at least through part of the engine's operating envelope.

31. A secondary fuelling system as claimed in any preceding claim in which the required quantity of secondary fuel is substantially proportional to quantity of the primary fuel supplied to the combustion chamber, at least through part of the engine's operating envelope.

32. A secondary fuelling system as claimed in claim 20 or claim 21 in which, above a predetermined threshold of primary fuelling, the required quantity of the secondary fuel decreases with increasing primary fuelling.

33. A secondary fuelling system as claimed in any preceding claim in which the required quantity of the secondary fuel, measured by mass, does not exceed fifteen percent of the primary fuel supplied to the combustion chamber.

34. An internal combustion engine provided with a secondary fuelling system according to any preceding claim.

35. An internal combustion engine as claimed in claim 35 which is a diesel engine comprising an engine control unit ("ECU") which monitors engine performance and controls engine operating parameters including timing of injection of the primary fuel in response, the ECU being configured to advance fuel injection when knocking is below a predetermined level, the secondary fuelling system being configured to supply the secondary fuel concurrently with or prior to injection of the primary fuel and thereby to suppress engine knocking, causing the ECU to advance injection of the primary fuel.

36. A motor vehicle comprising an internal combustion engine as claimed in claim 34 or claim 35.

37. A method, implemented in an internal combustion engine having a combustion chamber and a fuel injection system for injecting a primary fuel to the combustion chamber, of controlling delivery of a secondary fuel to the combustion chamber in addition to the primary fuel, the method comprising

determining an engine parameter indicative of quantity of primary fuel supplied to the combustion chamber,

calculating a required quantity of secondary fuel to be supplied to the combustion chamber as a function of the monitored engine parameter,

and supplying the required quantity of secondary fuel to the engine,

characterised in that at least for part of the time the determination of the engine parameter and the calculation of the required quantity of secondary fuel are made during each engine cycle and in that the required quantity of secondary fuel determined in one engine cycle is supplied to the combustion chamber in the same engine cycle or in the following engine cycle.

38. A method as claimed in claim 37 in which the required quantity of fuel determined in an engine cycle is supplied to the combustion chamber in the same engine cycle.

39. A method as claimed in claim 37 or claim 38 in which the monitored engine parameter is open time of a primary fuel injector of the engine.

40. A method as claimed in claim 39 in which monitoring open time of the primary fuel injector comprises counting pulses in a pulsed signal applied to the primary fuel injector.

41. A method as claimed in claim 40 in which counting pulses in the said pulsed signal comprises incrementing a first analogue electrical signal in response to each pulse counted.

42. A method as claimed in claim 41 further comprising providing a second analogue signal proportional to open time of the secondary fuel supply device during a secondary fuel supply event, comparing the first analogue signal to the second analogue signal, and causing closure of the secondary fuel supply device in response to that comparison.

43. A method as claimed in any of claims 37 to 43 comprising supplying the secondary fuel to the combustion chamber concurrently with injection of the primary fuel to the combustion chamber.

44. A method as claimed in any of claims 37 to 43 comprising responding to multiple injection events in a single engine cycle, calculating in respect of each injection event a required quantity of secondary fuel and opening and closing a secondary fuel supply device more than once during a single engine cycle to supply the required quantity of secondary fuel.

45. A method as claimed in any of claims 37 to 44 comprising initiating supply of the secondary fuel upon opening of a primary fuel injector of the engine, and continuing supply of the secondary fuel until the required quantity of secondary fuel has been delivered.

46. A method as claimed in claim 45 in which the rate of supply of secondary fuel is such that in any given injection event supply of the primary fuel ceases before the corresponding required quantity of secondary fuel has been delivered.

47. A method as claimed in any of claims 37 to 47 in which determination of the required quantity of secondary fuel is based upon open time of a primary fuel injector and upon fuel pressure applied to the primary fuel injector.

48. A method as claimed in claim 37 or claim 38 in which the monitored engine parameter is exhaust gas pressure.

49. A method as claimed in claim 48 in which sampling from an exhaust gas pressure sensor is coordinated with engine crank position whereby sampling is carried out during passage of a pressure wave through an exhaust of the engine.

50. A method as claimed in claim 49 in which the sampling is carried out over a predetermined time period which commences when the engine crank is at a predetermined angular position.

51. A method as claimed in claim 50 in which exhaust pressure values obtained during the predetermined time period are processed to provide a value indicative of the quantity of the primary fuel supplied in a single combustion cycle.

52. A method as claimed in claim 51 in which said processing comprises one or more of (a) low pass filtering; (b) averaging; and (c) obtaining a peak value.

53. A method as claimed in any of claims 49 to 52 in which timing of signals to at least one primary fuel injector of the engine is measured as an indicator of engine crank position.

54. A method as claimed in any of claims 37 to 53 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber takes place during the engine's induction stroke whilst an engine inlet valve associated with the combustion chamber is open and an engine exhaust valve associated with the combustion chamber is closed.

55. A method as claimed in claim 54 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber ends whilst the engine inlet valve and the engine outlet valve are both closed.

56. A method as claimed in any of claims 37 to 53 in which supply of secondary fuel is coordinated with injection of primary fuel to the combustion chamber but is retarded or advanced relative to it.

57. A method as claimed in any of claims 37 to 56 in which the required quantity of secondary fuel increases monotonically with quantity of the primary fuel injected to the combustion chamber, at least through part of the engine's operating envelope.

58. A method as claimed in any of claims 37 to 57 in which the required quantity of secondary fuel is substantially proportional to quantity of the primary fuel supplied to the combustion chamber, at least through part of the engine's operating envelope.

59. A method as claimed in claim 57 or 58 in which, above a predetermined threshold of primary fuelling, the required quantity of the secondary fuel decreases with increasing primary fuelling.

60. A method as claimed in any of claims 37 to 59 in which the required quantity of the secondary fuel, measured by mass, does not exceed fifteen percent of the primary fuel supplied to the combustion chamber.

61. A secondary fuelling system for fitting to an internal combustion engine, the engine comprising at least one combustion chamber, at least one primary fuel injector for injecting a primary fuel to the combustion chamber, and an electrical system which applies a pulsed injector control signal to the primary fuel injector to control its opening and closing, the secondary fuelling system being configured to supply a controlled quantity of a secondary fuel, in addition to the primary fuel, to the combustion chamber of the engine, the secondary fuelling system comprising

an electrical conductor for connection to the engine's electrical system to receive the injector control signal,

pulse counting circuitry configured to receive the injector control signal and to count pulses in the signal and provide a control output representing the pulse count, and

a supply controller configured to receive the control output and to control a secondary fuel supply device to supply to the combustion chamber a quantity of the secondary fuel which is determined on the basis of the control output.

62. A secondary fuelling system as claimed in claim 61 in which the said quantity of the secondary fuel delivered to the combustion chamber in an engine cycle is based on pulses counted in that engine cycle or in the preceding engine cycle.

63. A secondary fuelling system as claimed in claim 61 or claim 62 in which the electrical conductor is connected to the pulse counting circuitry through a high impedance path.

64. A secondary fuelling system as claimed in claim 63 in which the high impedance path incorporates a filter to remove high frequency spikes.

65. A secondary fuelling system as claimed in claim 63 or claim 64 in which the high impedance path incorporates a voltage limiting element to limit voltage applied to the pulse counting circuitry.

66. A secondary fuelling system as claimed in any of claims 63 to 65 in which the high impedance path leads to a logic gate to provide a square wave signal to the pulse counting circuitry.

67. A secondary fuelling system as claimed in any of claims 61 to 66 in which the pulse counting circuitry comprises a digital potentiometer which carries out the pulse counting and provides the control output, which takes the form of a voltage modulated analogue signal.

68. A secondary fuelling system as claimed in claim 67 in which the pulse counting circuitry further comprises a high frequency clock selectively connectable to the digital potentiometer to decrement its output to zero between injection events.

69. A secondary fuelling system as claimed in any of claims 61 to 68 in which the supply control circuitry comprises a timing circuit which outputs a second analogue signal proportional to open time of the secondary fuel supply device during a secondary fuel supply event and a comparator configured to compare the first analogue signal to the second analogue signal and to cause closure of the secondary fuel supply device in response to that comparison.

70. A secondary fuelling system as claimed in any of claims 61 to 69 configured to supply the secondary fuel to the combustion chamber concurrently with injection of the primary fuel to the combustion chamber.

71. A secondary fuelling system as claimed in any of claims 61 to 69 configured to respond to multiple injection events in a single engine cycle, counting pulses in each injection event and opening and closing the secondary fuel supply device more than once during a single engine cycle to supply the determined quantity of secondary fuel.

72. A secondary fuelling system as claimed in any of claims 61 to 71 configured to initiate supply of the secondary fuel upon opening of the primary fuel injector

of the engine, and to continue supply of the secondary fuel until the required quantity of secondary fuel has been delivered.

73. A secondary fuelling system as claimed in claim 71 or claim 72 in which rate of supply of secondary fuel is such that in any given injection event supply of the primary fuel ceases before the corresponding required quantity of secondary fuel has been delivered.

74. A secondary fuelling system as claimed in any of claims 61 to 73 in which the supply control circuitry receives a signal representing pressure of primary fuel applied to the primary fuel injector

75. A secondary fuelling system as claimed in any of claims 61 to 74 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber takes place during the engine's induction stroke whilst an engine inlet valve associated with the combustion chamber is open and an engine exhaust valve associated with the combustion chamber is closed.

76. A secondary fuelling system as claimed in claim 75 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber ends whilst the engine inlet valve and the engine outlet valve are both closed.

77. A secondary fuelling system as claimed in any of claims 61 to 70 in which supply of secondary fuel is coordinated with injection of primary fuel to the combustion chamber but is retarded or advanced relative to it.

78. A secondary fuelling system as claimed in any of claims 61 to 77 in which the quantity of secondary fuel supplied to the combustion chamber is substantially proportional to the pulse count, at least through part of the engine's operating envelope.

79. A secondary fuelling system as claimed in any of claims 61 to 78 in which the quantity of secondary fuel supplied to the combustion chamber, measured by mass, does not exceed fifteen percent of the primary fuel supplied to the combustion chamber.

80. An internal combustion engine provided with a secondary fuelling system according to any of claims 61 to 79.

81. An internal combustion engine as claimed in claim 80 which is a diesel engine comprising an engine control unit ("ECU") which monitors engine performance and controls engine operating parameters including timing of injection of the primary fuel in response, the ECU being configured to advance fuel injection when knocking is below a threshold, the secondary fuelling system being configured to supply the secondary fuel concurrently with or prior to injection of the primary fuel and thereby to suppress engine knocking, causing the ECU to advance injection of the primary fuel.

82. A method, implemented in an internal combustion engine comprising at least one combustion chamber, at least one primary fuel injector for injecting a primary fuel to the combustion chamber, and an electrical system which applies a pulsed injector control signal to the primary fuel injector to control its opening and closing, of controlling delivery of a secondary fuel to the combustion chamber in addition to the primary fuel, the method comprising

counting pulses in the injector control signal, and

controlling a quantity of the secondary fuel supplied to the combustion chamber based upon the pulse count.

83. A method as claimed in claim 82 in which the quantity of fuel delivered to the combustion chamber in an engine cycle is based on pulses counted in that engine cycle or in the preceding engine cycle.

84. A method as claimed in claim 82 or claim 83 comprising supplying the secondary fuel to the combustion chamber concurrently with injection of the primary fuel to the combustion chamber.

85. A method as claimed in any of claims 82 to 84 comprising responding to multiple injection events in a single engine cycle by counting pulses in each injection event and delivering multiple quantities of the secondary fuel to the combustion chamber in response.

86. A method as claimed in any of claims 82 to 85 comprising initiating supply of the secondary fuel upon opening of the primary fuel injector of the engine, and continuing supply of the secondary fuel until the required quantity of secondary fuel has been delivered.

87. A method as claimed in any of claims 82 to 86 in which rate of supply of secondary fuel is such that in any given injection event supply of the primary fuel ceases before the corresponding required quantity of secondary fuel has been delivered.

88. A method as claimed in any of claims 82 to 87 in which control of the quantity of the secondary fuel is additionally based upon pressure of primary fuel applied to the primary fuel injector.

89. A method as claimed in any of claims 82 to 88 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber takes place during the engine's induction stroke whilst an engine inlet valve associated with the combustion chamber is open and an engine exhaust valve associated with the combustion chamber is closed.

90. A method as claimed in claim 89 in which supply of secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber ends whilst the engine inlet valve and the engine outlet valve are both closed.

91. A method as claimed in any of claims 82 to 88 in which supply of secondary fuel is coordinated with injection of primary fuel to the combustion chamber but is retarded or advanced relative to it.

92. A method as claimed in any of claims 82 to 91 in which the quantity of secondary fuel supplied to the combustion chamber is substantially proportional to the pulse count, at least through part of the engine's operating envelope.

93. A method as claimed in any of claims 82 to 92 in which the quantity of secondary fuel supplied to the combustion chamber, measured by mass, does

not exceed fifteen percent of the primary fuel supplied to the combustion chamber.

94. A secondary fuelling system for fitting to an internal combustion engine, the internal combustion engine being configured to be fuelled with a primary fuel and the secondary fuelling system being configured to supply a controlled quantity of a secondary fuel, in addition to the primary fuel, to a combustion chamber of the engine, the secondary fuelling system comprising a supply controller for monitoring one or more engine operating parameters and determining in response a required rate of delivery of the secondary fuel, and a proportional valve controlled by the supply controller to supply the secondary fuel at the required rate.

95. A secondary fuelling system as claimed in claim 94 in which the secondary fuel is supplied via the proportional valve to an air intake of the engine.

96. A secondary fuelling system as claimed in claim 95 in which the secondary fuel is supplied to the air intake of the engine downstream of a turbocharger.

97. A secondary fuelling system as claimed in any of claims 94 to 96 in which the supply controller receives sensor signals indicative of either or both of

(a) secondary fuel pressure and

(b) secondary fuel temperature

and adjusts opening of the proportional valve on the basis of the sensor signals to achieve the required rate of delivery of the secondary fuel.

98. A secondary fuelling system as claimed in claim 94 or claim 95 in which the supply controller applies a pulse width modulated signal to the proportional valve to control rate of delivery of the secondary fuel.

99. A secondary fuelling system as claimed in any of claims 94 to 98 in which supply of the secondary fuel is continuous, at least through a part of the engine's operating envelope.

100. A secondary fuelling system as claimed in any of claims 94 to 99 in which the proportional valve has a continuously variable valve opening.

101. A secondary fuelling system as claimed in any of claims 94 to 100 in which the rate of supply of the secondary fuel increases monotonically with the quantity of the primary fuel injected to the combustion chamber in a combustion cycle, at least through part of the engine's operating envelope.

102. A secondary fuelling system as claimed in any of claims 94 to 101 in which the rate of supply of the secondary fuel is substantially proportional to quantity of the primary fuel supplied to the combustion chamber in a combustion cycle, at least through part of the engine's operating envelope.

103. A secondary fuelling system as claimed in claim 101 or claim 102 in which, above a predetermined threshold of primary fuelling, the rate of supply of the secondary fuel decreases with increasing primary fuelling.

104. A secondary fuelling system as claimed in any preceding claim in which the quantity of the secondary fuel, measured by mass, does not exceed fifteen percent of the primary fuel supplied to the combustion chamber.

105. A secondary fuelling system for fitting to an internal combustion engine, the engine comprising at least one combustion chamber and at least one primary fuel injector for injecting a primary fuel to the combustion chamber, the secondary fuelling system being configured to supply a controlled quantity
5 of a secondary fuel, in addition to the primary fuel, to the combustion chamber of the engine, the secondary fuelling system comprising

at least one pressure sensor for mounting in an exhaust of the engine to provide a sensor output indicative of exhaust pressure, and

a supply controller configured to receive the sensor output and to control a
10 secondary fuel supply device to supply to the combustion chamber a quantity of the secondary fuel which is determined on the basis of the sensor output.

106. A secondary fuelling system as claimed in claim 105 in which the said quantity of the secondary fuel delivered to the combustion chamber in an engine cycle is based on pressure sensed in that engine cycle or in the preceding engine cycle.

- 5 107. A secondary fuelling system as claimed in claim 105 or claim 106 configured to supply the secondary fuel to the combustion chamber concurrently with injection of the primary fuel to the combustion chamber.

108. A secondary fuelling system as claimed in any of claims 105 to 107 in which supply of secondary fuel to the combustion chamber is coordinated
10 with engine valve timing such that supply of the secondary fuel to the combustion chamber takes place during the engine's induction stroke whilst an engine inlet valve associated with the combustion chamber is open and an engine exhaust valve associated with the combustion chamber is closed.

109. A secondary fuelling system as claimed in claim 108 in which supply of
15 secondary fuel to the combustion chamber is coordinated with engine valve timing such that supply of the secondary fuel to the combustion chamber ends whilst the engine inlet valve and the engine outlet valve are both closed.

110. A secondary fuelling system as claimed in any of claims 105 to 107 in which supply of secondary fuel is coordinated with injection of primary fuel to
20 the combustion chamber but is retarded or advanced relative to it.

111. A secondary fuelling system as claimed in any of claims 105 to 110 in which the quantity of secondary fuel supplied to the combustion chamber, measured by mass, does not exceed fifteen percent of the primary fuel supplied to the combustion chamber.

25 112. A secondary fuelling system as claimed in and of claims 105 to 111 in which sampling from the pressure sensor is coordinated with engine crank position whereby sampling is carried out during passage of a pressure wave

through an exhaust of the engine.

113. A secondary fuelling system as claimed in claim 112 in which sampling is carried out over a predetermined time period which commences when the engine crank is at a predetermined angular position.

- 5 114. A secondary fuelling system as claimed in claim 112 or 113 in which exhaust pressure values obtained during the predetermined time period are processed to provide a value indicative of the quantity of the primary fuel supplied in a single combustion cycle.

- 10 115. A secondary fuelling system as claimed in claim 114 in which said processing comprises one or more of (a) low pass filtering; (b) averaging; and (c) obtaining a peak value.

116. A secondary fuelling system as claimed in any of claims 112 to 115 in which timing of signals to at least one primary fuel injector of the engine is measured as an indicator of engine crank position.

- 15 117. A secondary fuelling system as claimed in any of claims 105 to 116 in which the pressure sensor is a filter pressure sensor associated with a particulate filter in the exhaust.

- 20 118. A secondary fuelling system as claimed in claim 117 which comprises a further pressure sensor mountable in the exhaust, and in which a signal from the further pressure sensor is modified based on the signal from the filter pressure sensor, to compensate for changes in flow resistance in the exhaust that take place over time.

- 25 119. A method, implemented in an internal combustion engine comprising at least one combustion chamber and at least one primary fuel injector for injecting a primary fuel to the combustion chamber, and an exhaust, of controlling delivery of a secondary fuel to the combustion chamber in addition to the primary fuel, the method comprising

monitoring pressure in the exhaust, and

controlling a quantity of the secondary fuel supplied to the combustion chamber based upon the exhaust pressure.

120. A method as claimed in claim 119 in which the said quantity of the
5 secondary fuel delivered to the combustion chamber in an engine cycle is
based on pressure sensed in that engine cycle or in the preceding engine
cycle.

121. A method as claimed in claim 119 or claim 120 comprising supplying the
secondary fuel to the combustion chamber concurrently with injection of the
10 primary fuel to the combustion chamber.

122. A method as claimed in any of claims 119 to 121 in which supply of
secondary fuel to the combustion chamber is coordinated with engine valve
timing such that supply of the secondary fuel to the combustion chamber
takes place during the engine's induction stroke whilst an engine inlet valve
15 associated with the combustion chamber is open and an engine exhaust
valve associated with the combustion chamber is closed.

123. A method as claimed in any of claims 119 to 122 in which supply of
secondary fuel to the combustion chamber is coordinated with engine valve
timing such that supply of the secondary fuel to the combustion chamber ends
20 whilst the engine inlet valve and the engine outlet valve are both closed.

124. A method as claimed in any of claims 119 to 123 in which supply of
secondary fuel is coordinated with injection of primary fuel to the combustion
chamber but is retarded or advanced relative to it.

125. A method as claimed in any of claims 119 to 124 in which the quantity
25 of secondary fuel supplied to the combustion chamber, measured by mass,
does not exceed fifteen percent of the primary fuel supplied to the combustion
chamber.

126. A method as claimed in any of claims 119 to 126 in which sampling from the pressure sensor is coordinated with engine crank position whereby sampling is carried out during passage of a pressure wave through an exhaust of the engine.

- 5 127. A method as claimed in any of claims 119 to 126 in which sampling is carried out over a predetermined time period which commences when the engine crank is at a predetermined angular position.

128. A method as claimed in claim 127 or claim 128 in which exhaust pressure values obtained during the predetermined time period are processed to
10 provide a value indicative of the quantity of the primary fuel supplied in a single combustion cycle.

129. A method as claimed in claim 128 in which said processing comprises one or more of (a) low pass filtering; (b) averaging; and (c) obtaining a peak value.

- 15 130. A method as claimed in any of claims 119 to 129 in which timing of signals to at least one primary fuel injector of the engine is measured as an indicator of engine crank position.

131. A method as claimed in any of claims 119 to 130 in which the pressure sensor is a filter pressure sensor associated with a particulate filter in the
20 exhaust.

132. A method as claimed in any of claims 119 to 131 in which a further pressure sensor is mounted in the exhaust, and in which a signal from the further pressure sensor is modified based on the signal from the filter pressure sensor, to compensate for changes in flow resistance in the exhaust
25 that take place over time.

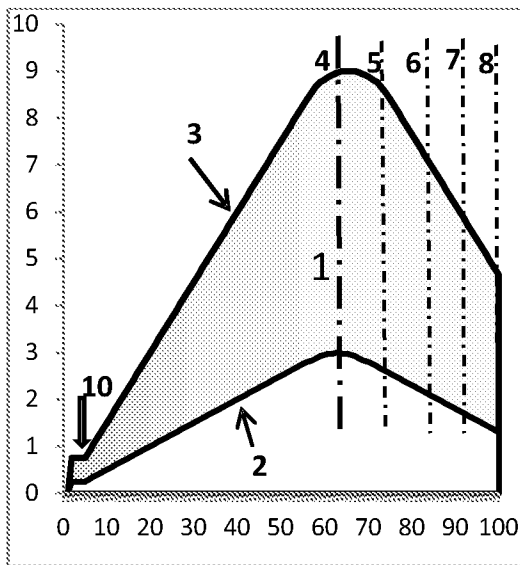


Figure 1/19

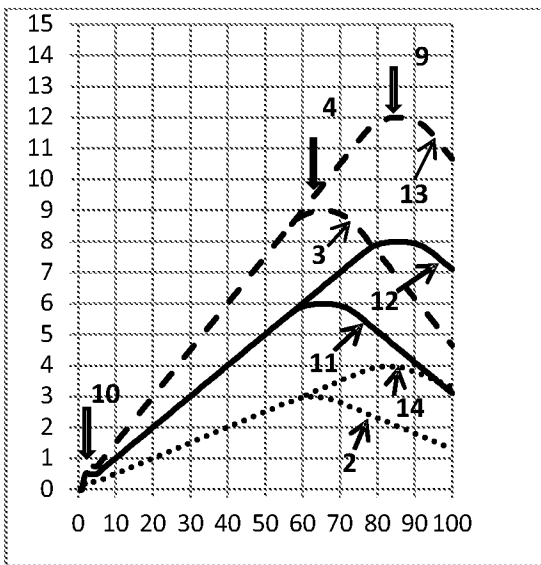


Figure 2/19

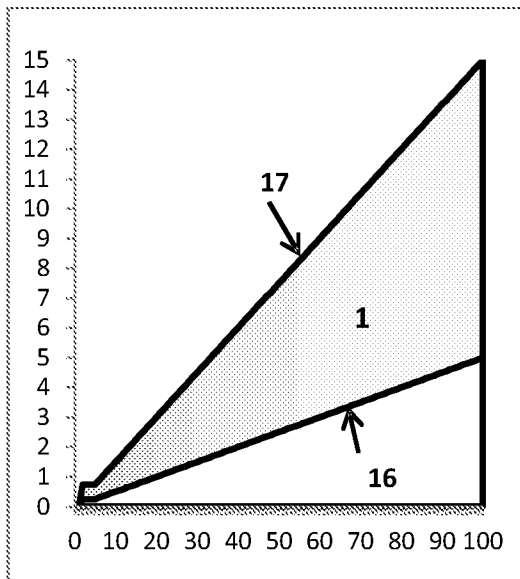


Figure 3/19

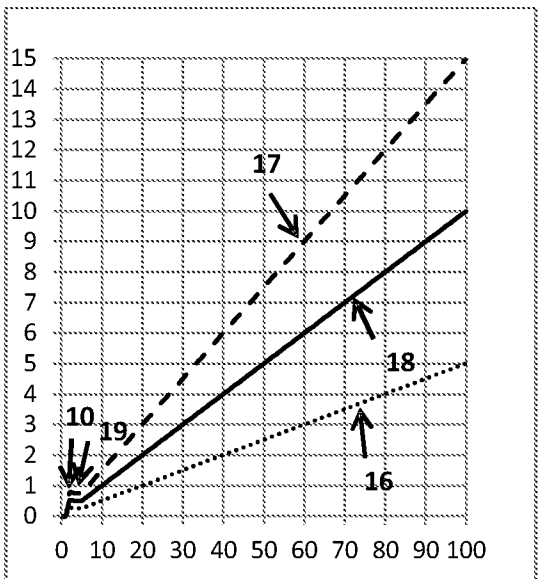


Figure 4/19

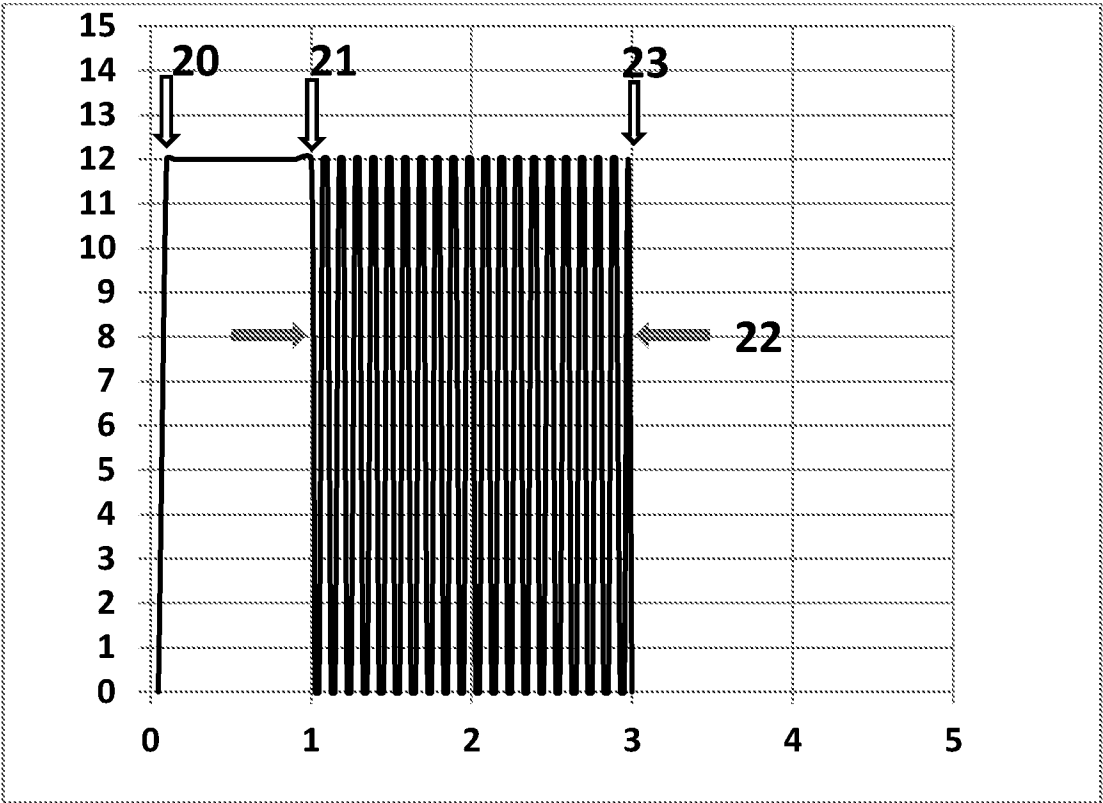


Figure 5/19

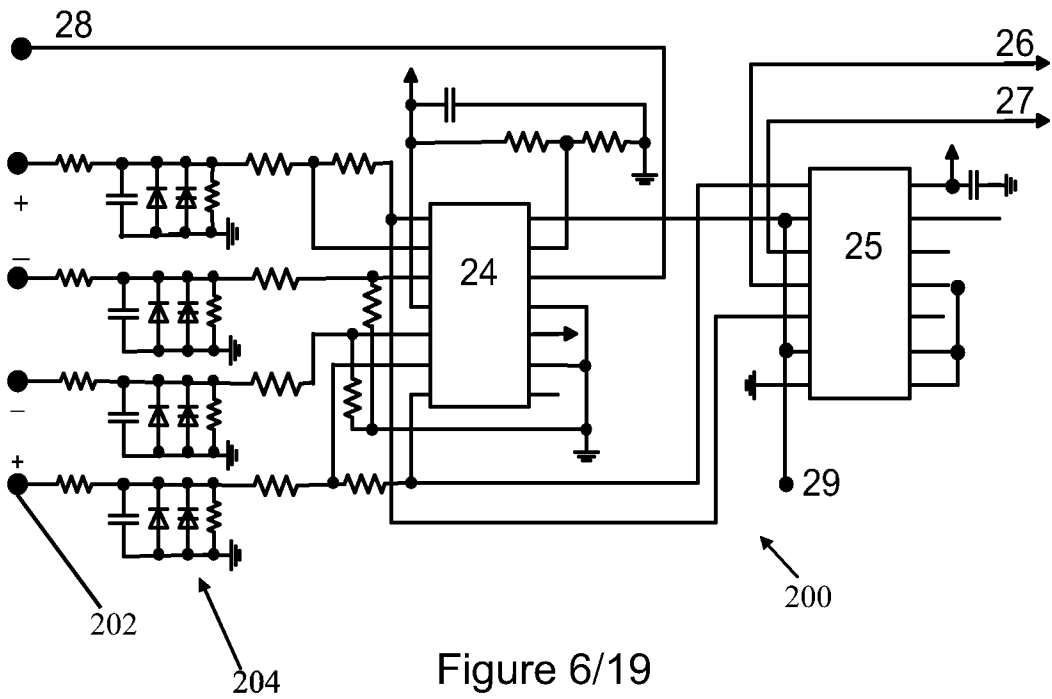


Figure 6/19

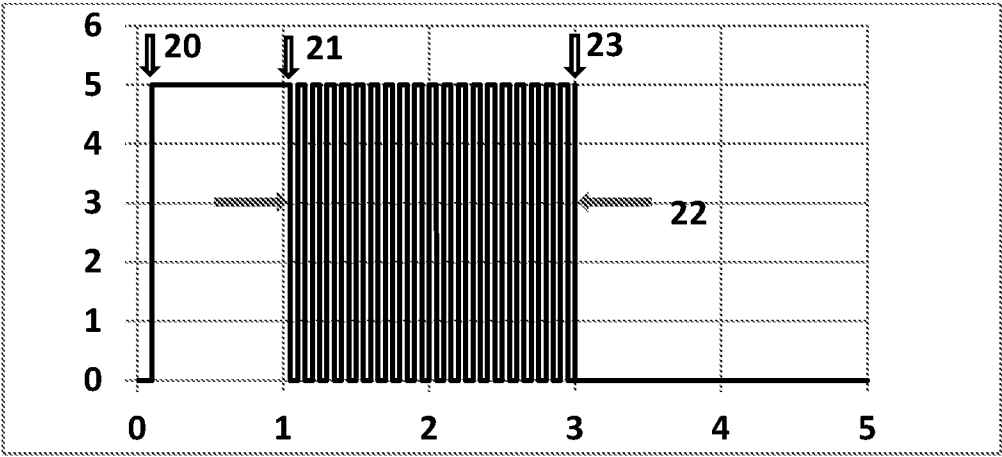


Figure 7/19

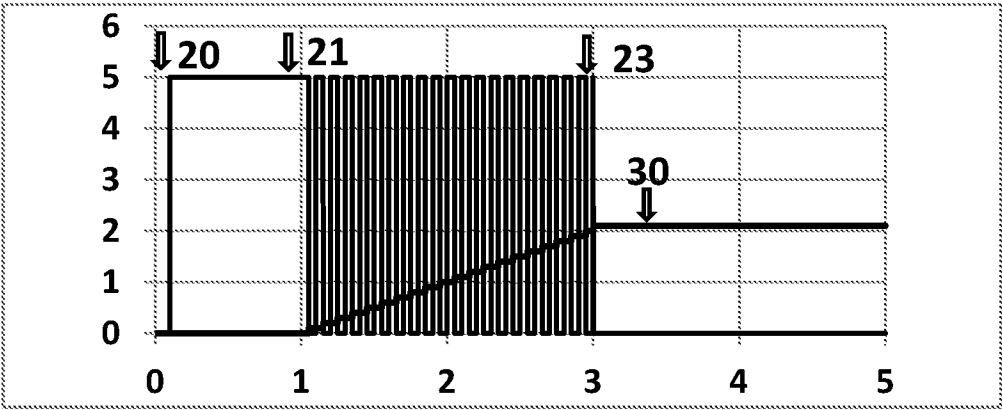


Figure 8/19

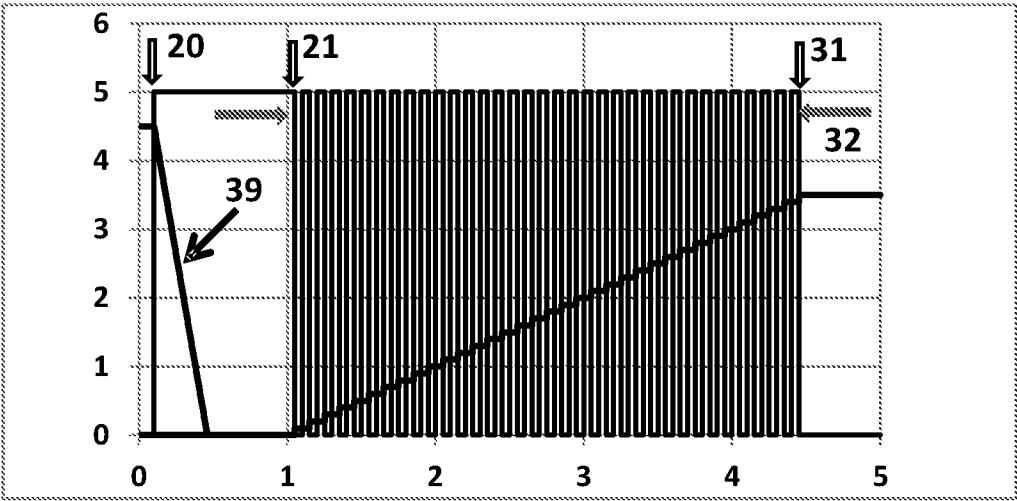


Figure 9/19

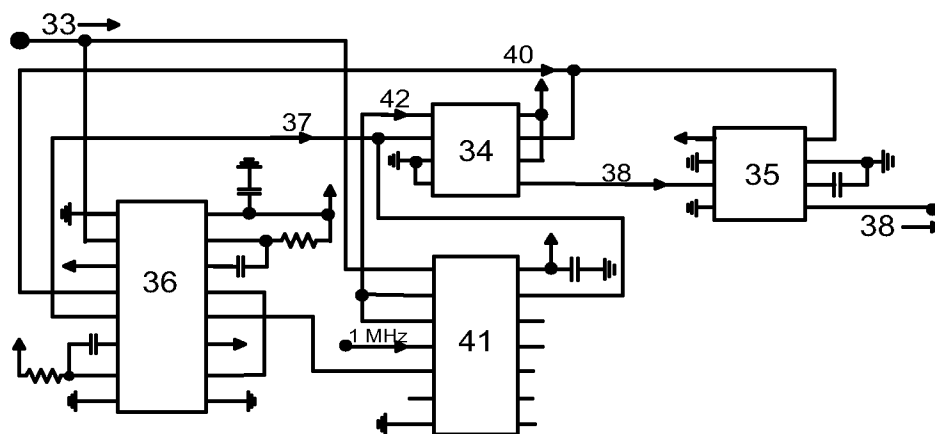


Figure 10/19

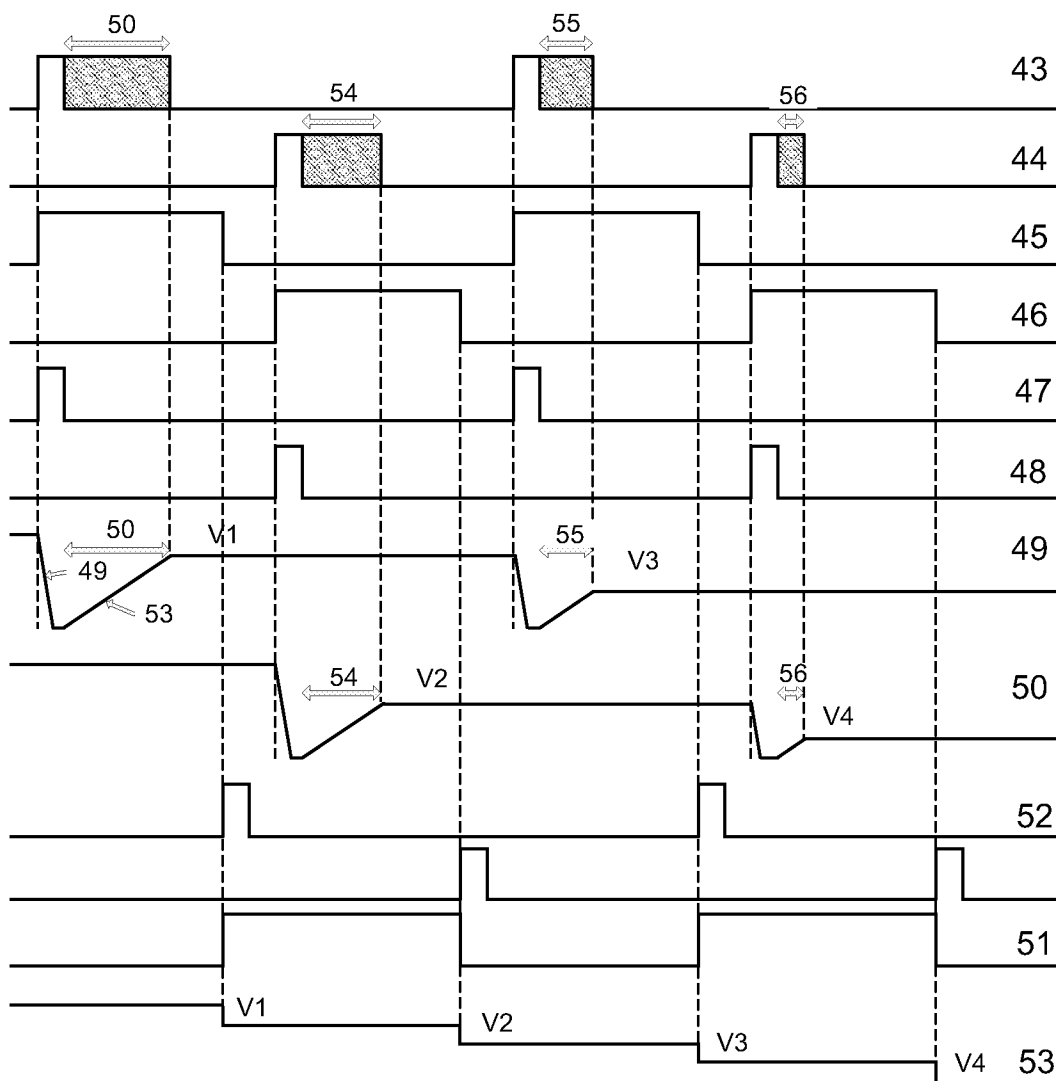


Figure 11/19

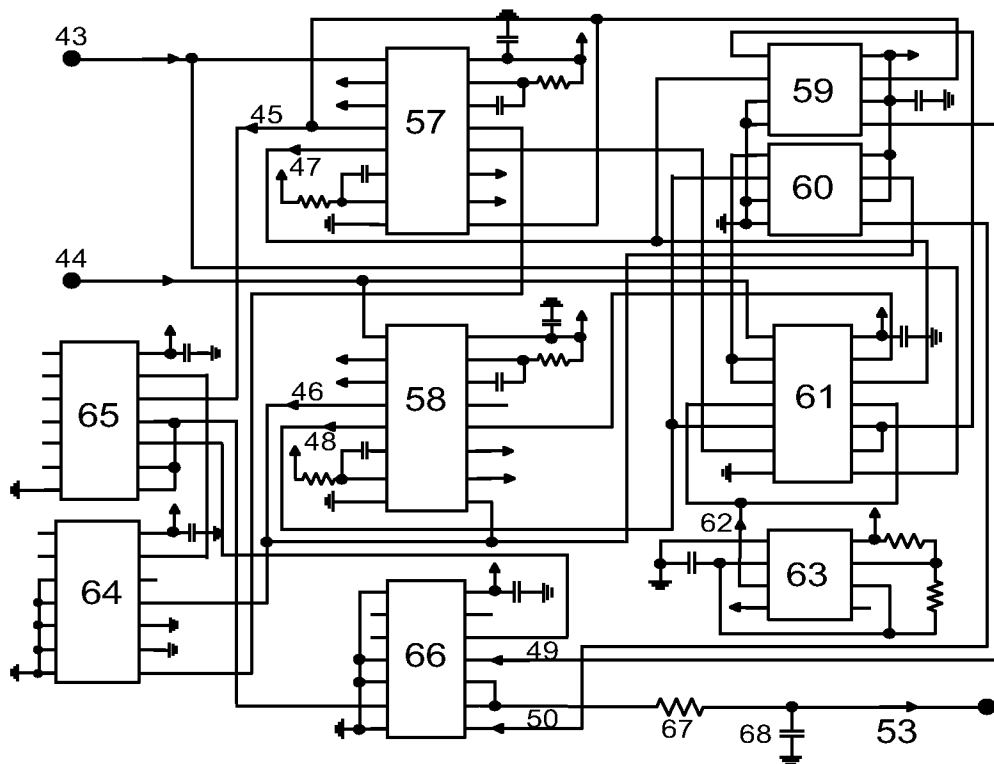


Figure 12/19

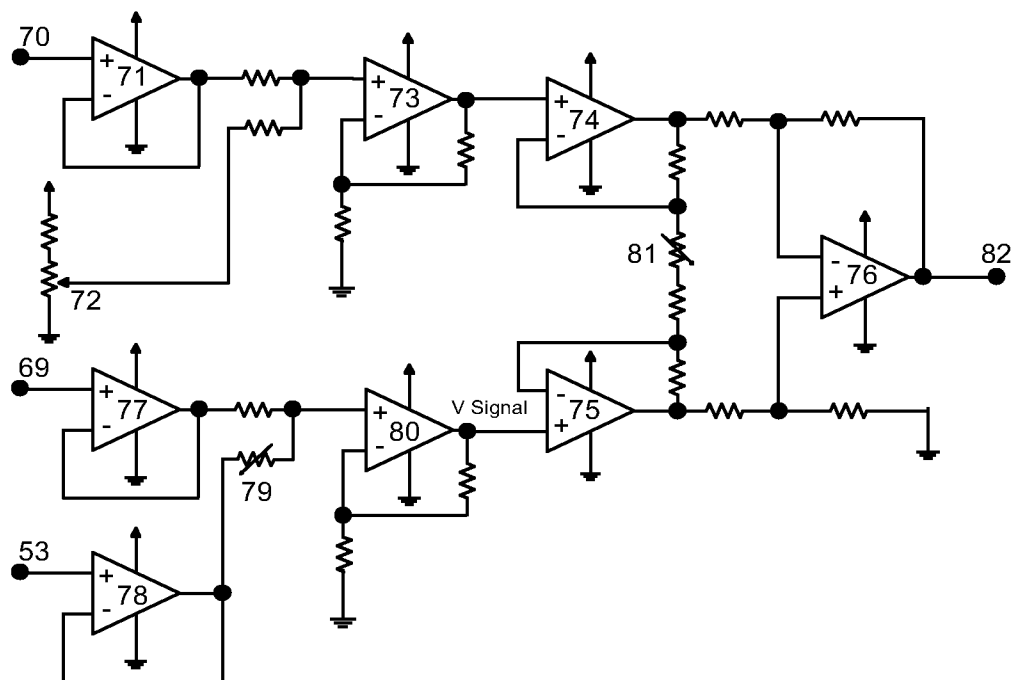


Figure 13/19

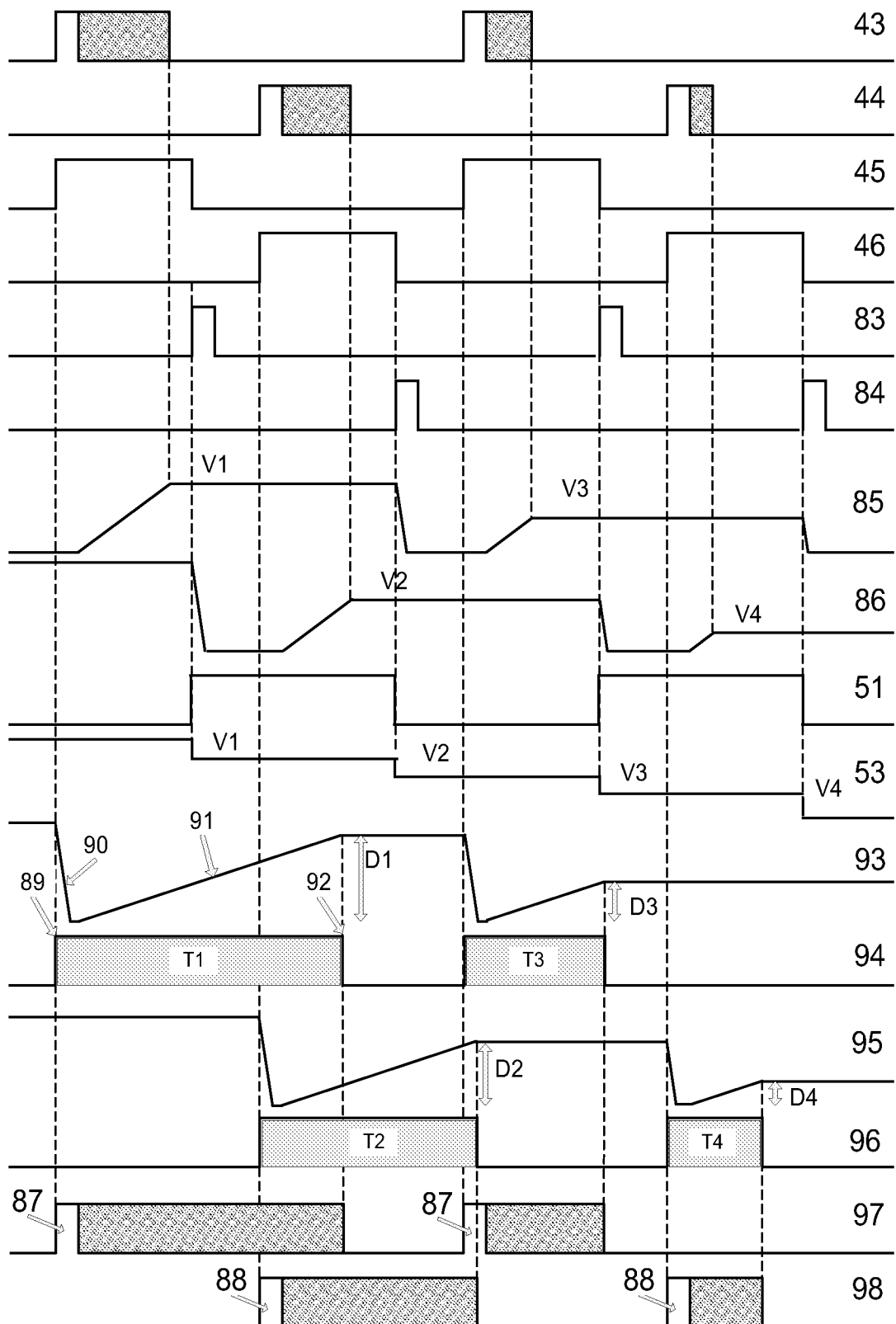


Figure 14/19

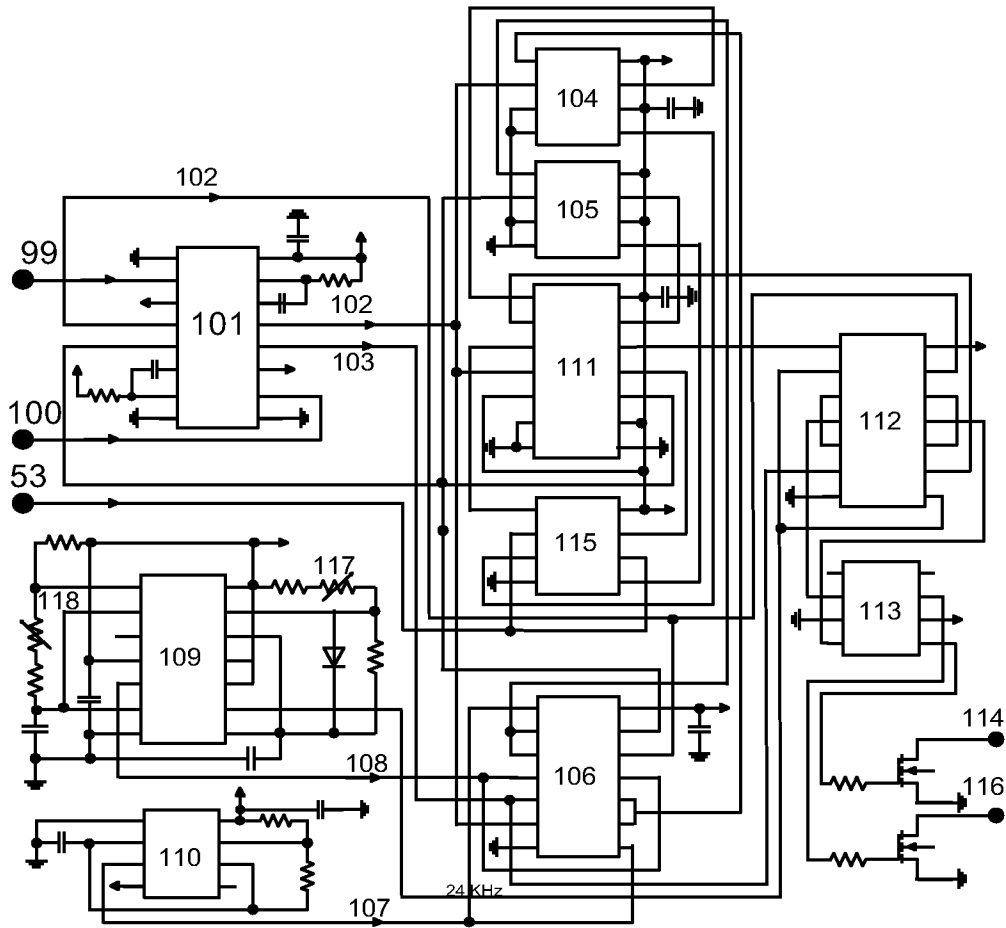


Figure 15/19

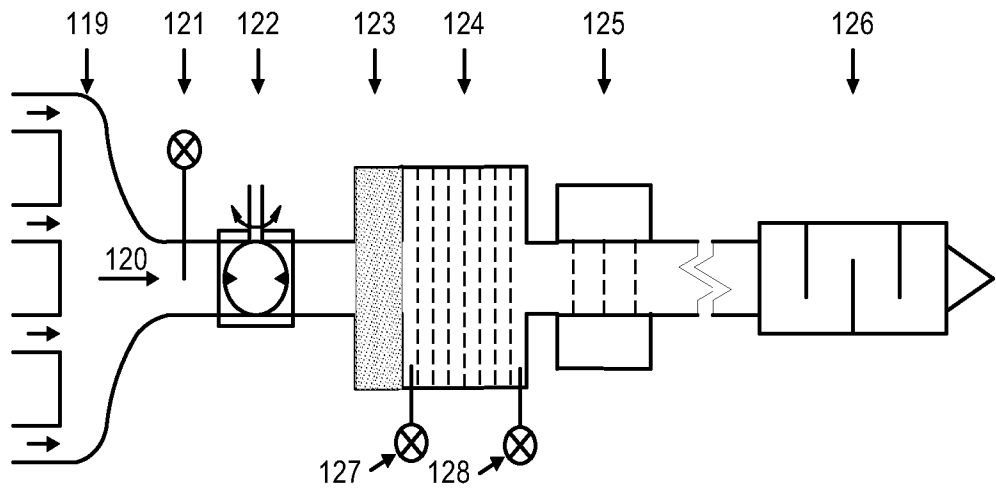


Figure 16/19

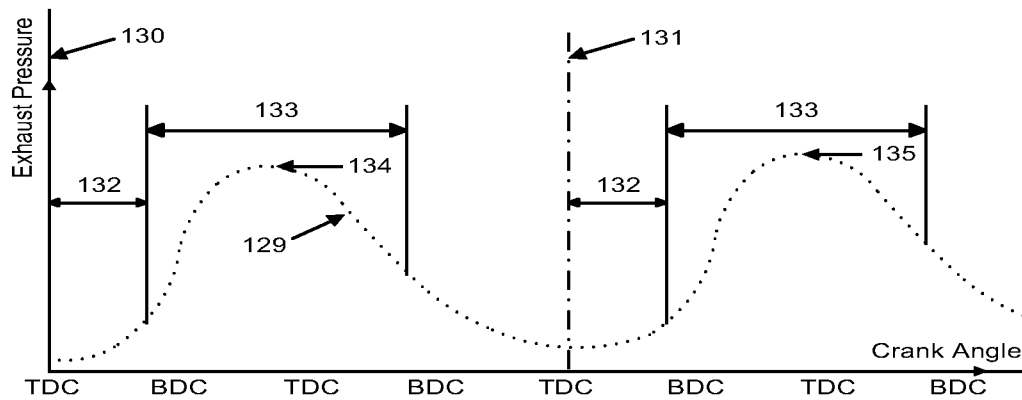


Figure 17/19

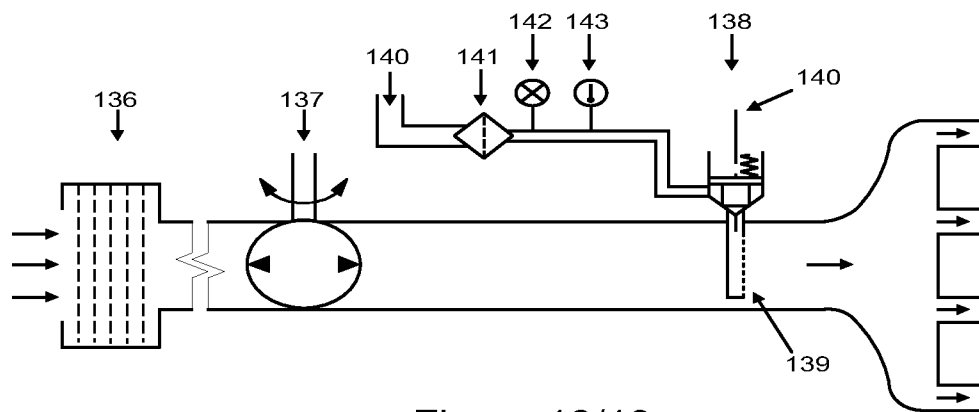


Figure 18/19

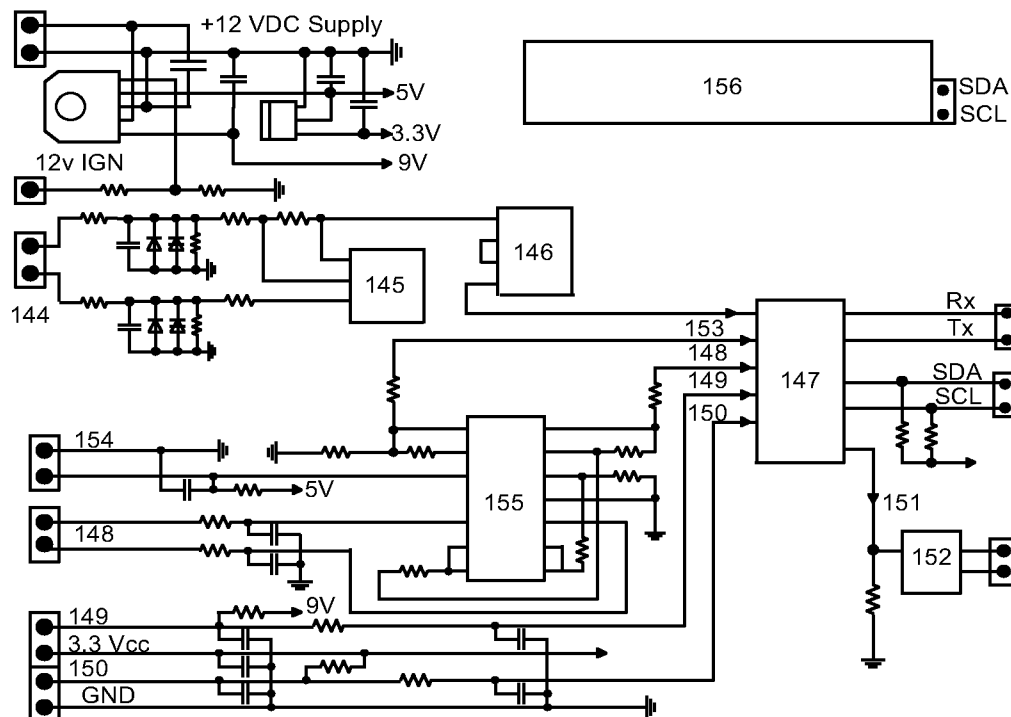


Figure 19/19