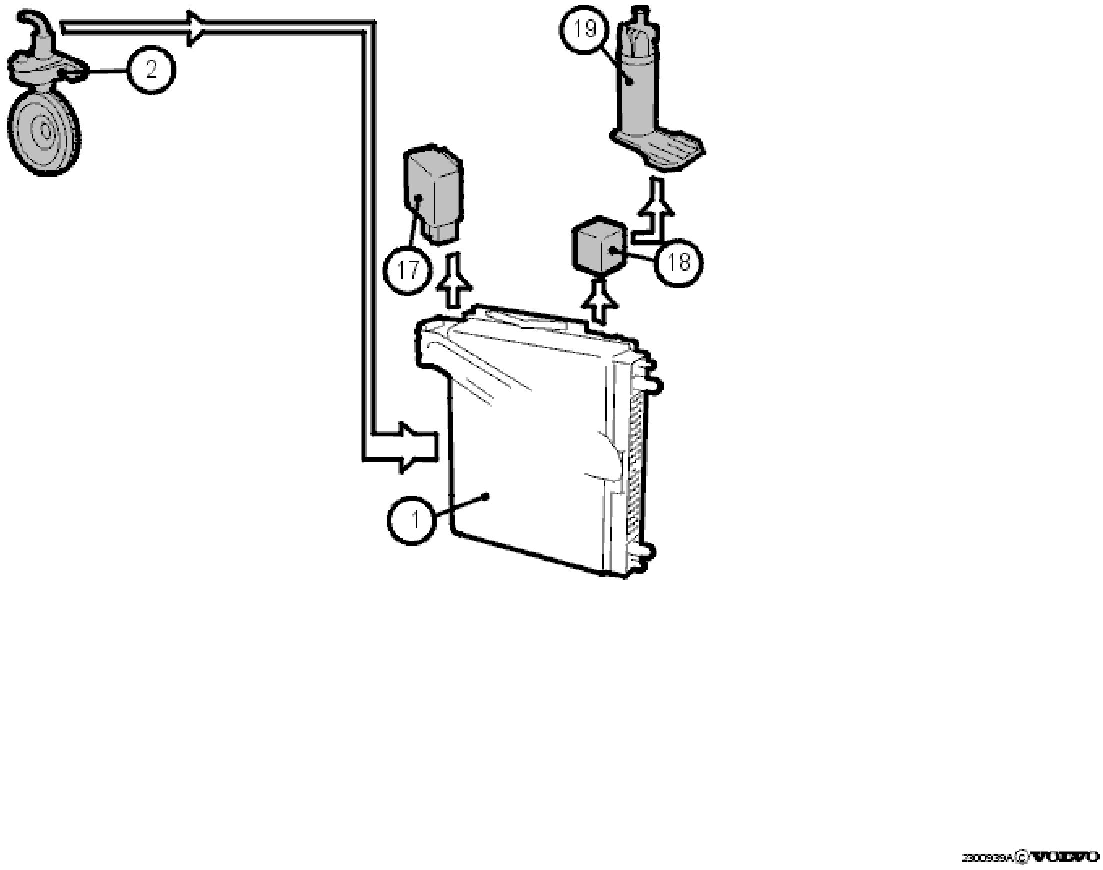
Fuel control



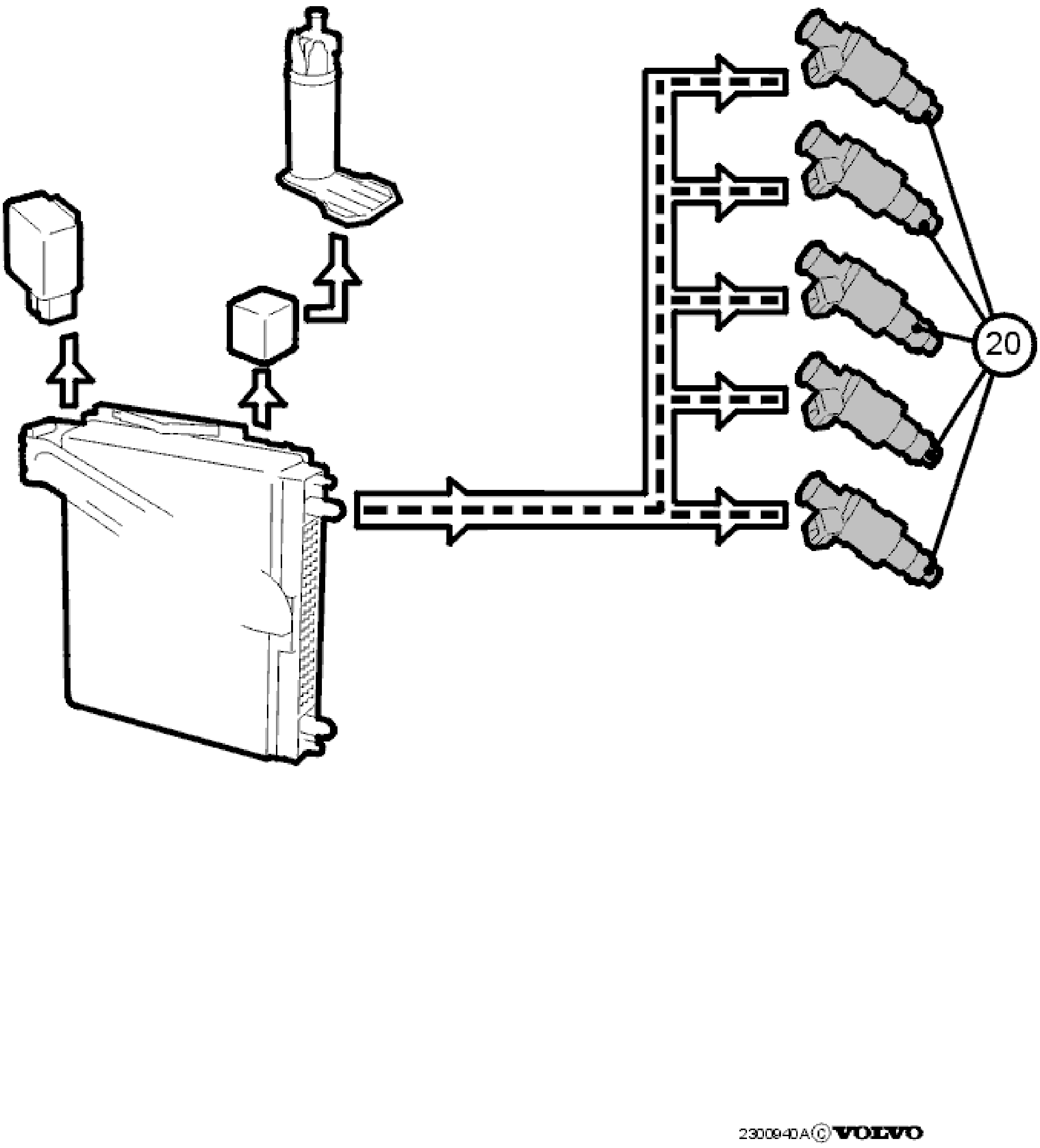
The fuel injection system tasks

- To provide fuel
- To distribute the fuel between the cylinders
- To provide the correct quantity of fuel

Starting fuel pump (FP)

The control module (1) activates the system relay (17) when the ignition is switched on. The relay provides the various components in the system with voltage, for example the injectors, idle air control (IAC) valve and pump relay (18).

On many systems the control module activates the pump relay (18) and therefore the fuel pump (FP) (19) for a few seconds when the ignition is switched on. This is so that the fuel pressure builds up.
The engine must turn for the relay and pump to be reactivated by the control module. The control module receives the signals for this from the engine speed (RPM) sensor (2).



How is the quantity of fuel regulated?

the injectors (20) are supplied with power (+) via the system relay.

The control module regulates the quantity of fuel by grounding the injectors. The longer the ground pulse the longer the opening time and therefore the greater the supply of fuel.

In principle, the length of the ground pulse can vary between 0 ms during engine braking up to approximately 100 ms (100/1000 second) during rapid acceleration.

Because the system voltage affects the speed at which the valves open, the control module adapts the ground pulse accordingly.

In order for the quantity of fuel to be correct, it is also a precondition that the fuel pressure is correct.

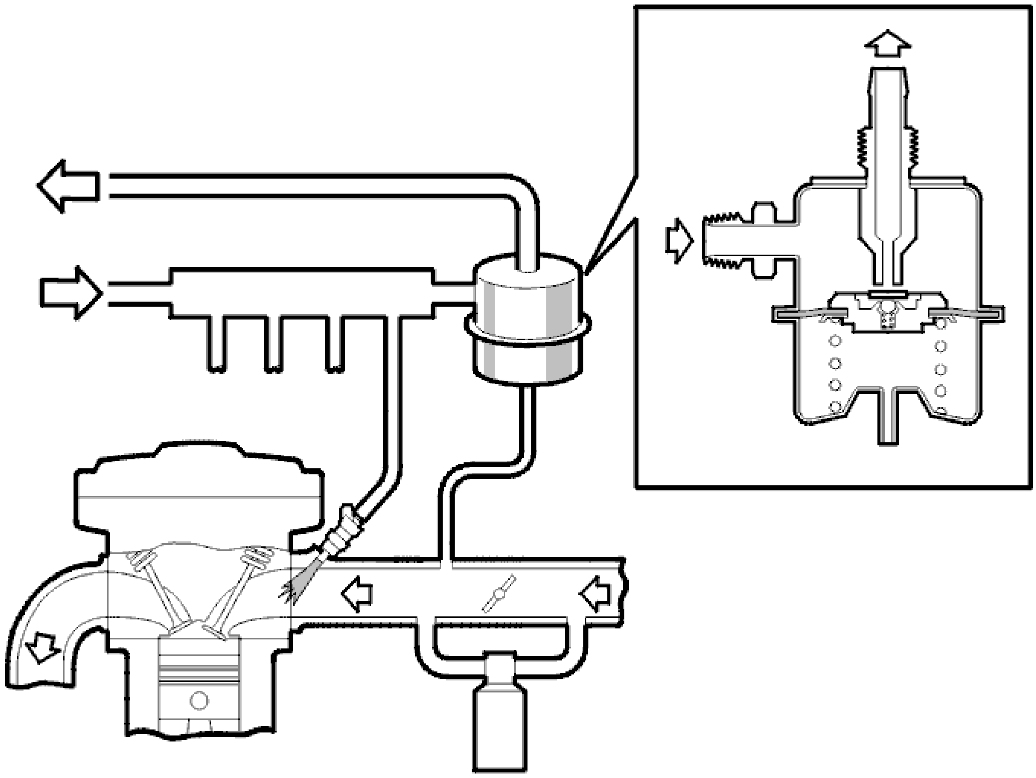
The three main different types of fuel

system

Mono point (= one-point). There is a centrally located injector, usually in the throttle body (TB).

Multi point (= several points). Several injectors, normally one per cylinder, located as close to the intake valves as possible.

Sequential injection. In many systems all the injectors open at the same time or in groups. In sequential systems each injector is regulated and opened individually.



Regulating fuel pressure

When engine load varies, the pressure in the intake manifold also varies. The fuel then encounters shifting resistance. Therefore the ease with which the fuel is able to come out of the injectors varies.

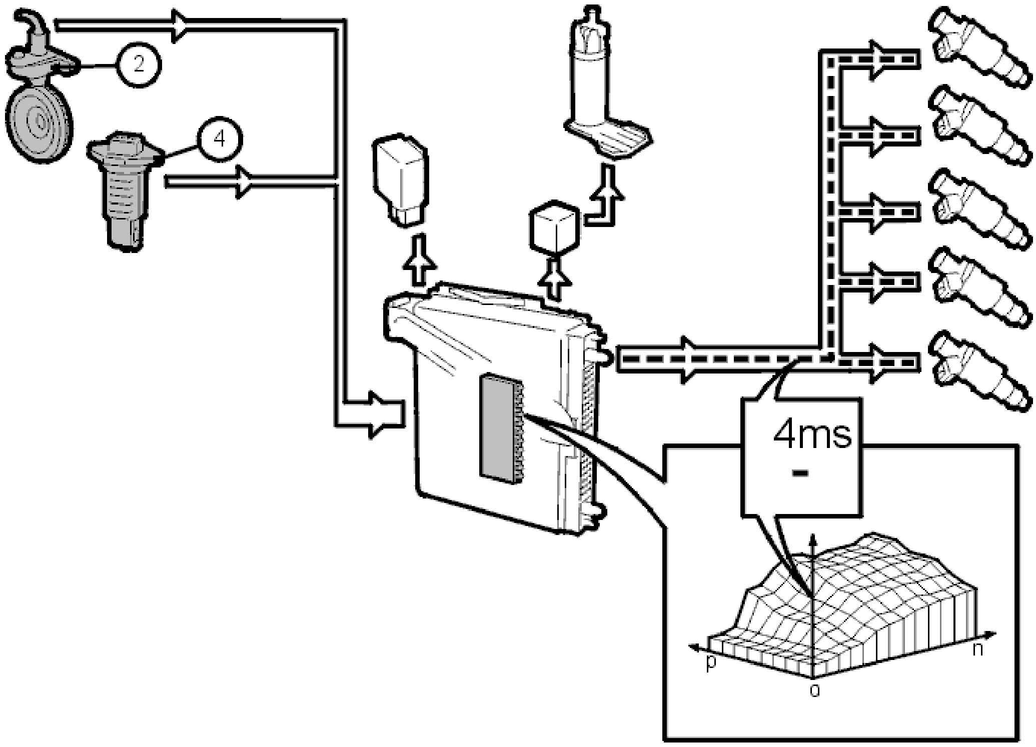
It is only the injector opening time which should affect the quantity of fuel. Therefore the fuel pressure must be regulated in relation to the pressure in the intake manifold.

The fuel pressure regulator is affected by the pressure in the intake manifold. It regulates the fuel pressure so that it is always kept at a constant level above the pressure in the intake manifold. Excess fuel is guided back to the fuel tank.

the injectors are connected to a distributor rail which has a large volume of fuel. This is so that the fuel pressure is not dramatically affected when the injectors open.

Thanks to the pressure regulator, it is only the injector opening time calculated by the control module that affects the quantity of fuel.

What is the correct quantity of fuel?
Signals from a number of sensors are required in order for the correct quantity of fuel to be calculated.
Which are the most important sensors?



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The basic volume of fuel

The two most important sensors are the engine speed (RPM) sensor (2) and the volume air flow (VAF) sensor (4).

The control module reads of the signals from these two sensors and is then able to determine how much air enters the engine per engine revolution. It then reads its own memory to check what the opening time or the basic quantity should be, 4 ms for example.

90° before top dead center (TDC) for cylinder 1, the control module receives a special signal from the engine speed (RPM) sensor. The number of degrees before top dead center (TDC) may vary depending on the type of system. The control module is then able to calculate when it should open the injectors. Note that on systems with sequential injection an additional sensor is required for this.

The signal from the engine speed (RPM) sensor is also used to control the engine speed (RPM) limiter. In other words when the injection should be shut off.

Differentiate between air flow and engine load

Air flow: The volume of air per time unit
Load: The volume of air used by each cylinder.

- Low load: Low air flow and high engine speed (RPM).
- High load: Large air flow and low engine speed (RPM).

Different methods for the measurement of air flow

Mass air flow (MAF) sensors which measure the air mass (kg). The mass air flow (MAF) sensor also takes into account the volume of oxygen using the air temperature and pressure.

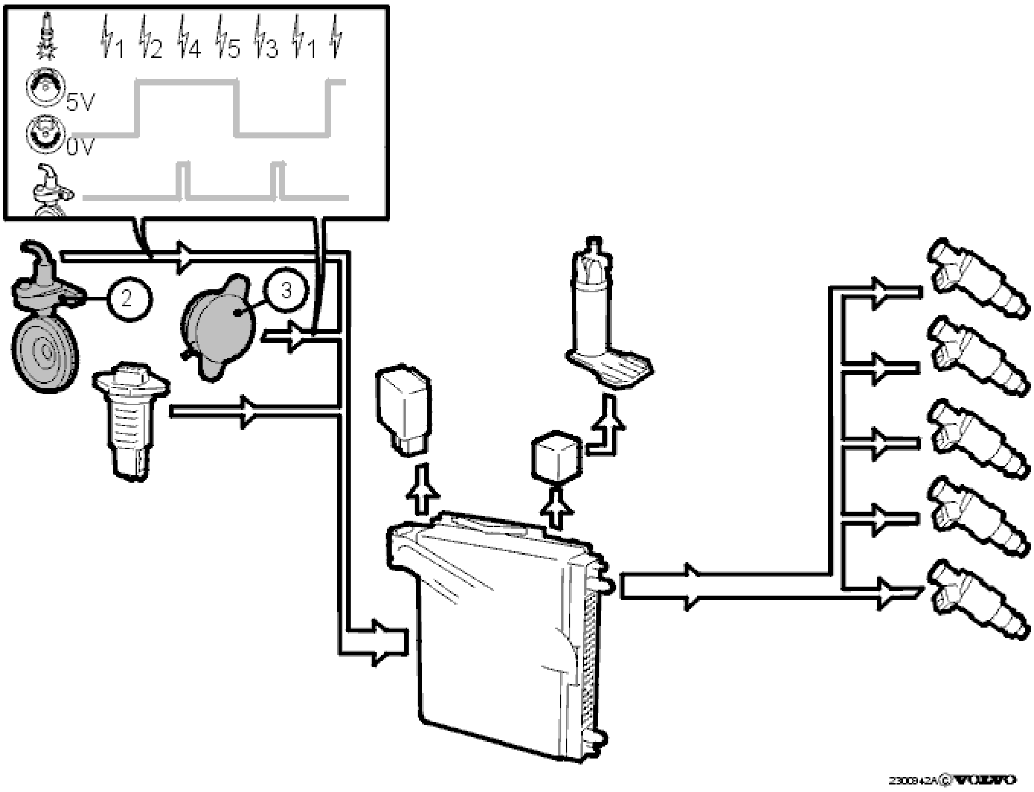
Mass air flow (MAF) sensors which measure the air volume (dm^3/$inch^3$).

Pressure gauges which measure the pressure in the intake manifold (kPa/psi).

The air volume and therefore the pressure in the intake manifold is affected by the air temperature. Therefore both the mass air flow (MAF) sensor and the pressure gauge must be supplemented with an intake air temperature (IAT) sensor.

14 kg of dry air at normal pressure is the equivalent of:

- 12174 dm^3 (l) air at +20 °C (68°F))
- 10853 dm^3 at 0 °C (32°F)



Camshaft position (CMP) sensor

On engines with sequential injection the control module must determine which of the injectors should be opened.

Two signals are required for this.

A signal from the engine speed (RPM) sensor (2) when cylinder 1 are approximately 90° before top dead center (TDC).

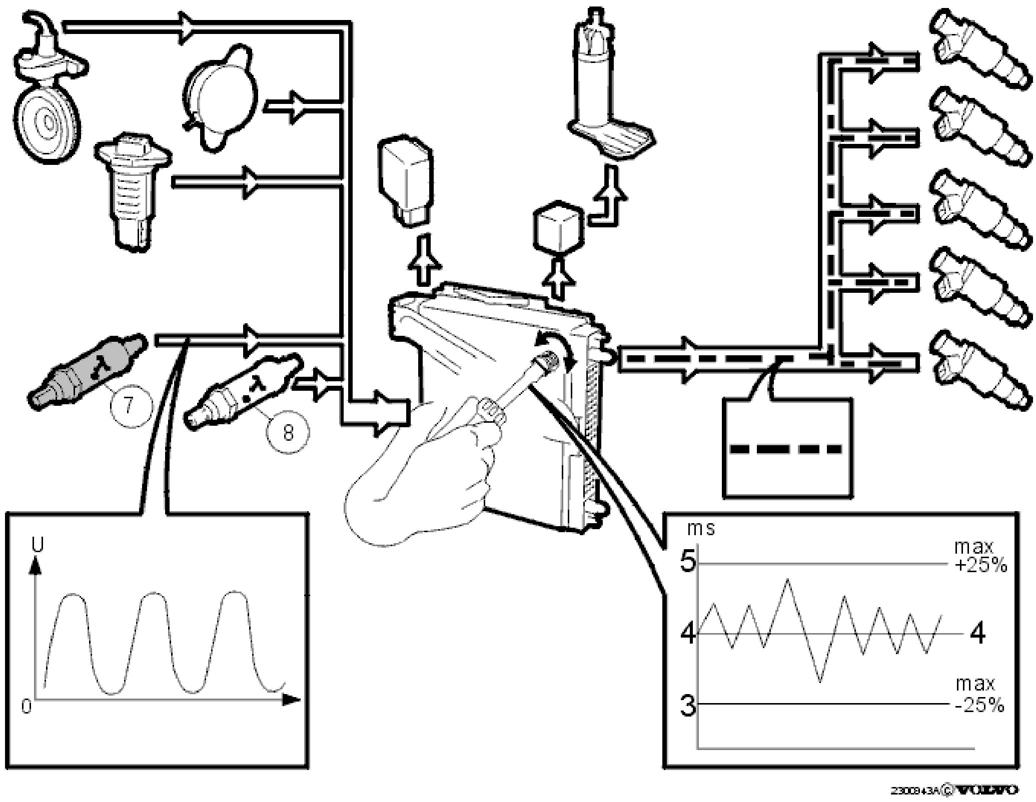
A signal which indicates whether the crankshaft is in the first or second revolution of the operating cycle. These signals come from the camshaft position (CMP) sensor (3).

In certain ignition systems the camshaft position (CMP) sensor is also used as a sensor.

What is an operating cycle?

An operating cycle is when all cylinders have ignited once. For this to happen the crankshaft must rotate twice. The camshaft rotates at half the speed of the crankshaft. In other words it has rotated once during one operating cycle.

The camshaft position (CMP) sensor provides a type of signal during the first crankshaft revolution in an operating cycle and another type of signal during the second revolution. This allows the control module to monitor whether the engine is in the first or second revolution of an operating cycle.



Correcting the quantity of fuel

The efficiency of combustion can vary depending on the fuel quality and the condition of the engine amongst other things. This also means that the composition of the exhaust gases varies.

On cars with three-way catalytic converter (TWC) the exhaust gases must have a certain composition for optimal three-way catalytic converter (TWC) efficiency.

Oxygen sensor (HO2S)

Irrespective of combustion efficiency, there is always a little oxygen (O_2 left in the exhaust gases. The oxygen Sensor (7), which is also called the heated oxygen sensor (HO2S), measures the oxygen content of the exhaust gases.

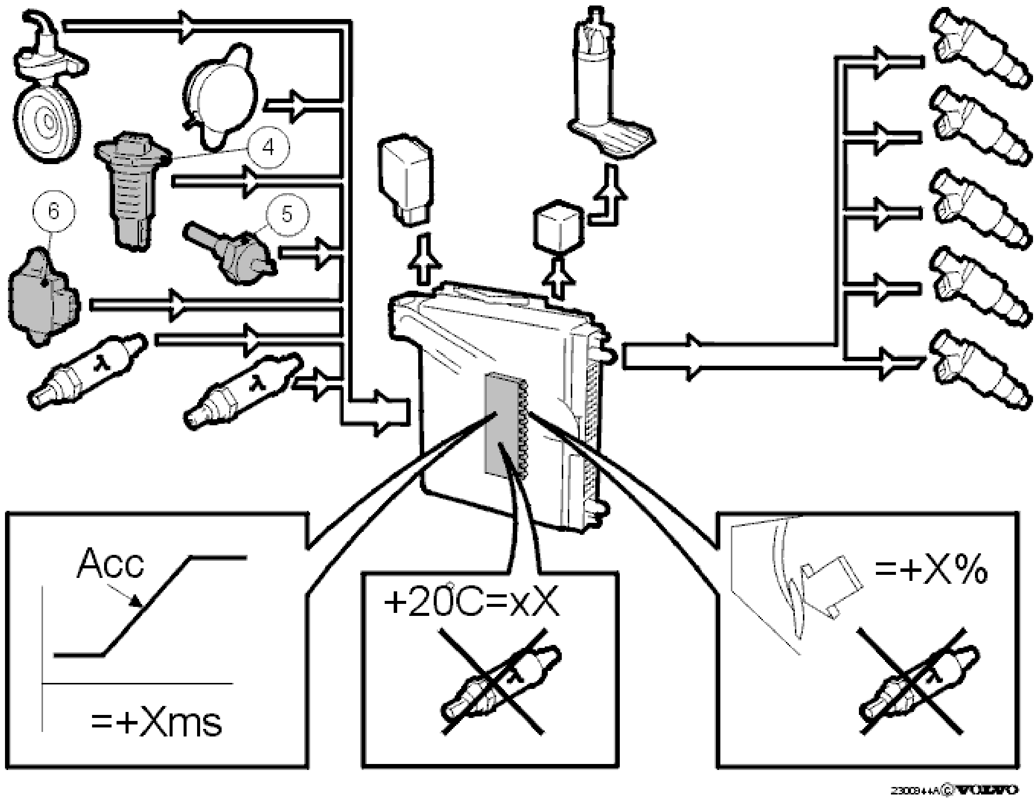
The control module finely adjusts the quantity of fuel using the signal from the oxygen sensor (HO2S).
The control module is able to adjust the basic quantity of fuel by +/- 25% based on the signals from the oxygen sensor (HO2S).
Assume that the basic quantity corresponds to an injector opening time of 4 ms. The oxygen sensor (HO2S) can act on this so that it becomes a minimum of 3 ms or a maximum of 5 ms.

"Fuel trim"

The control module responds immediately to the signal from the oxygen sensor (HO2S). It either increases or reduces the injector opening time. As a result the fuel / air mixture will at one moment contain too little fuel and shortly afterwards too much fuel. However the average value will be close to the ideal value, in other words λ = 1. Because the fuel / air mixture changes rapidly from lean to rich, the signal from the oxygen sensor (HO2S) will oscillate.

Rear oxygen sensor (HO2S)

Certain systems have 2 oxygen sensors (HO2S). The second sensor (8) is then position downstream of the three-way catalytic converter (TWC). The purpose of the rear oxygen sensor (HO2S) is to provide even finer adjustment of the quantity of fuel.
Furthermore the control module is able to check the efficiency of the three-way catalytic converter (TWC). This is done by comparing the signals from both the sensors.



Compensating the quantity of fuel

Under certain conditions the engine requires more fuel than during normal operating conditions, at start, when the engine is cold, during acceleration and at wide open throttle (WOT) for example.

The control module reads off these conditions via a number of sensors and compensates the quantity of fuel as necessary.

The engine sometimes runs slightly rich, and during this time the control module ignores the signals form the oxygen sensor (HO2S).

Start

A rich mixture is required to guarantee good starting.

There are programmed values in the control module memory. These are used for start in different conditions.

During the actual start the control module does not normally take into account the air flow. It only checks the engine speed (RPM) and the temperature of the engine coolant.

Cold engine

When the engine is cold the friction in the engine is greater. Furthermore some of the fuel condenses and attaches to the cold engine surfaces such as in the intake manifold, on the inlet ducts and the cylinders for example.

The engine coolant temperature (ECT) sensor (5) measures the engine coolant temperature (ECT).

There are programmed values in the control module memory. These indicate how much the basic quantity of fuel should be increased depending on how cold the engine is.

There are different values for cold start and the warming up period for example.

- Cold start: When the starter motor turns the cold engine and when the fuel / air mixture should be ignited.
- The warming up period: The time after start until the engine has reached normal operating temperature.

Acceleration

More fuel is required during acceleration for two reasons. Partly to obtain as high engine power as possible, partly so that the air speed in the intake manifold increases rapidly. Fuel is heavier than air. Therefore fuel does not accelerate as rapidly. With normal fuel regulation this may result in the mixture being too lean. In order to compensate for this, a temporary increase in the quantity of fuel is required.

When the volume air flow (VAF) sensor (4) indicates that the air flow increases rapidly the control module understands that there is acceleration and increases the quantity of fuel. The amount of additional fuel required depends on how heavy the acceleration is.

On systems with mass air flow (MAF) sensors of the hot film type, it is the signal from the throttle position (TP) sensor (6) that indicates to the control module that there is acceleration. (There are two different version of mass air flow (MAF) sensor, the hot film type or the hot wire type, depending on whether it is a wire or film that senses the air mass).

Wide open throttle / full load

More fuel is required during wide open throttle / full load for two reasons.
To obtain maximum power. This is normally obtained at a λ value of approximately 0.9. To lower the combustion and exhaust gas temperatures.

The throttle position (TP) sensor (6) indicates that the throttle is completely open. The control module responds by extending the injector opening time.

On turbocharged engines the information from the volume air flow (VAF) sensor is normally used instead of the signals from the throttle position (TP) sensor to determine whether full load enrichment should be activated or not. This is because a turbocharged engine has extremely high thermal load. Therefore the mixture must be enriched even before wide open throttle (WOT).

On certain turbocharged engines there is a temperature sensor. This measures the exhaust temperature and controls the engagement of full load enrichment.

Engine braking

During engine braking the fuel can be shut off so that fuel consumption is lower and the exhaust gases cleaner. The conditions for the control module to shut off the fuel are:

- The throttle is closed.
- The engine speed (RPM) is above a certain level.
- The engine is at normal operating temperature.

On certain systems the control module also takes account of the gear selected in order to determine whether the fuel shut-off system should be engaged or not. This is to avoid activation of the fuel shut-off system in the lowest gears. The control module can determine which gear is selected by comparing the current information about the vehicle speed and engine speed (RPM). Alternatively the engine control module (ECM) receives the information directly from the automatic transmission control module (TCM).

We now have a fuel system which adapts the quantity of fuel to the different driving conditions.