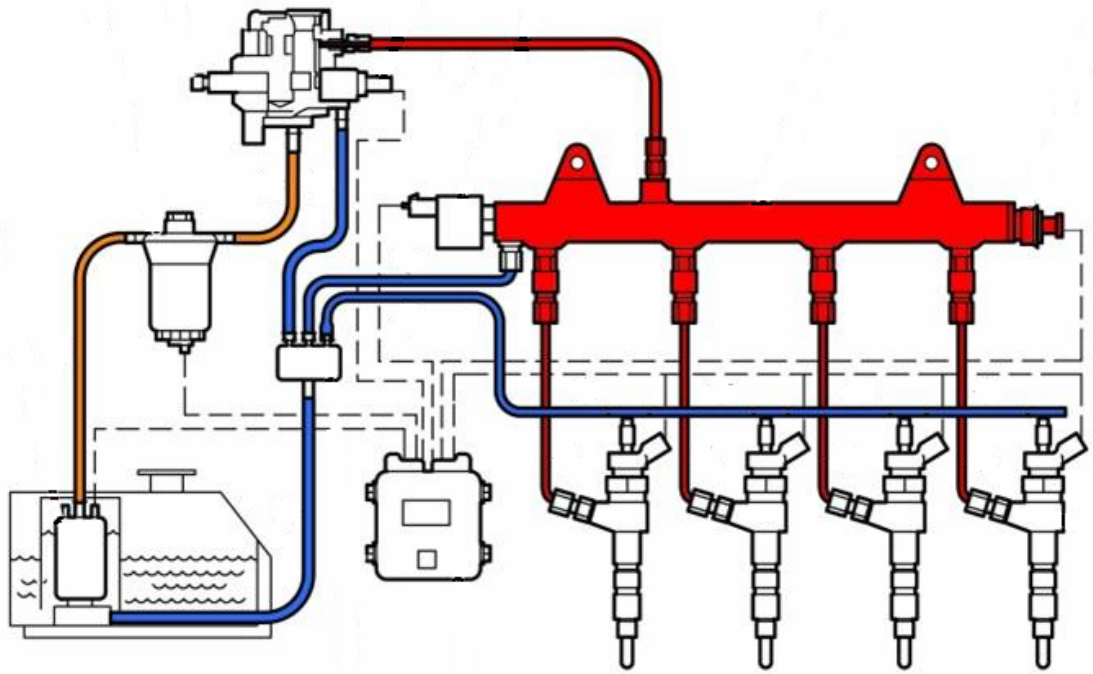
# Welcome

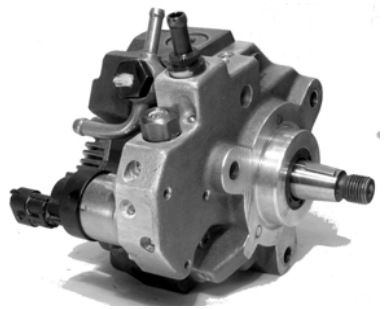
## to a technical overview of

# Common Rail Diesel Fuel Systems



presented by

**Tony Kitchen**
**(AK Training)**



## Foreword

Tony Kitchen (AK Training) offers professional technical courses for those working in the motor industry wanting to improve their knowledge and skills and who are serious about personal development. Courses are based upon 25 years practical experience and extensive hands on technical knowledge of subject matter (not possible to obtain from reading a book or watching a CD)!

A comprehensive programme of courses is available from AK Training. Courses run from regular venues in the Milton Keynes, Northampton and Buckingham area. Courses can also be delivered on site at clients premises anywhere in the UK. Overseas training services are also available. This presentation forms the basis for a generic common rail diesel course which is now undergoing development and will be available in the near future.

For further information about courses, course dates, fees, venues and all other enquiries including on site and overseas training, please contact AK Training direct. In the meantime, please enjoy the following presentation for your technical information.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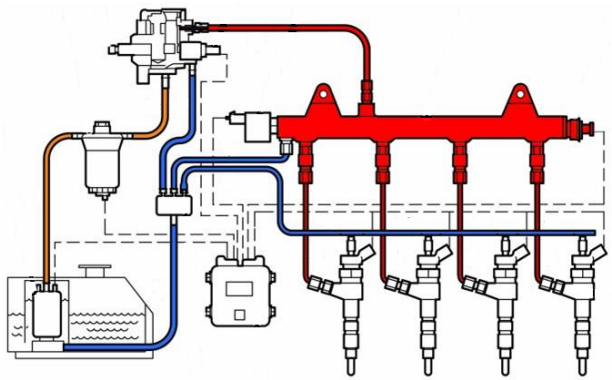
# Common Rail Diesel Fuel Systems

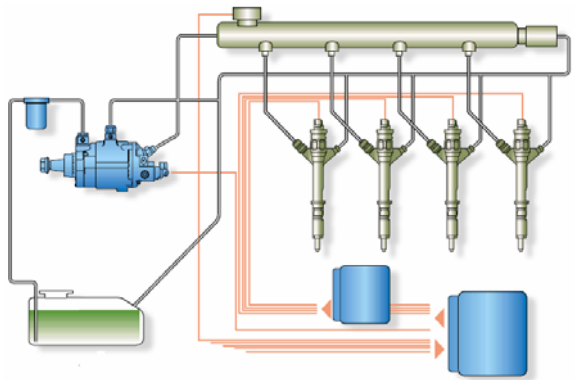
## Aims, objectives and disclaimer:

The aim of this presentation is to give a generic technical overview of the main features and operating principles of the common rail diesel fuel injection system. The objectives are that by the end of this presentation, you will have gained a working knowledge and understanding of the fundamental principles of common rail diesel fuel systems.

Please bear in mind that all facts and figures quoted are intended to show typical examples only for explanation purposes. Always refer to manufacturer technical data for exact system specifications and repair procedures.

Finally this slide show does not include speaker notes. If you have any comments or would like further information, please contact AK Training directly





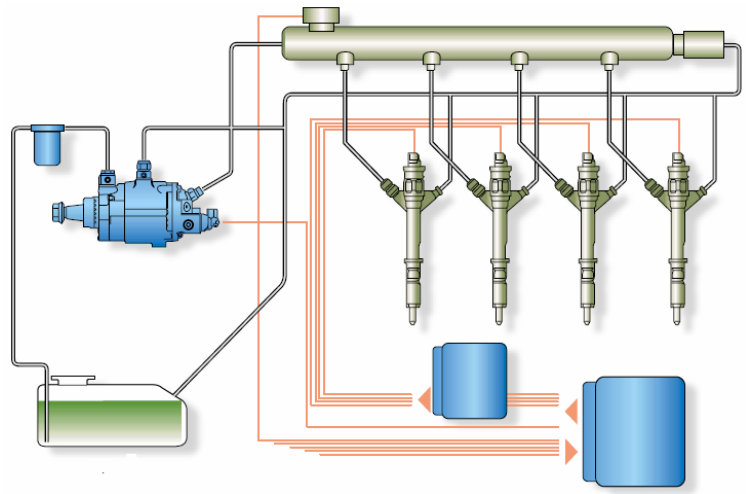
# Common Rail Diesel Fuel Systems

Advantages of common rail:

- Fuel pressure available on demand.....
- Higher injection pressures and finer atomization of fuel.....
- Injection pressure created independent of engine speed.....
- Multiple injections per cylinder combustion are possible.

Benefits of common rail:

- Reduction of overall exhaust emissions.....
- Reduction of particulate emissions.....
- Reduction of noise emissions.....
- Improved fuel efficiency.....
- Higher performance.



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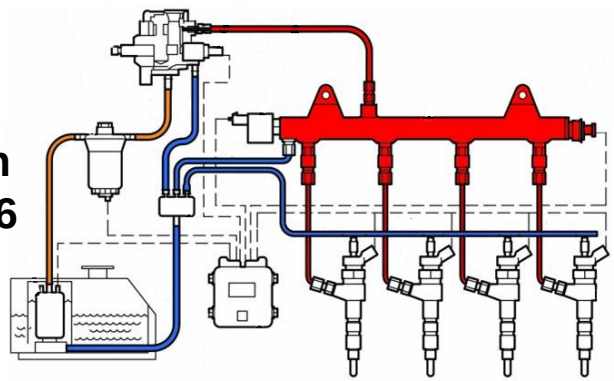
# Common Rail Diesel Fuel Systems

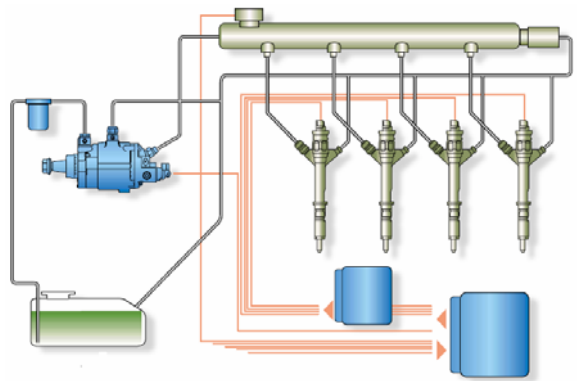
Examples of typical common rail system maximum fuel pressures:

- **Bosch:** Generation 1: up to 1350 Bar (19845 psi). Unijet
  Generation 2: up to 1600 Bar (23520 psi) EDC 16
  Generation 3: up to 2000 Bar + (29400 psi)
- **Denso:** 1st generation: up to 1450 Bar (21315 psi) ECD-U2P
  2nd generation: 1800 Bar + (26460 psi) HP3/HP4
- **Delphi** Multec: up to 2000 Bar
  Direct acting diesel common rail system: up to 2000 Bar

Various systems differ in design, components layout and specific functions. However, all operate in a similar way.

**Bosch EDC16**



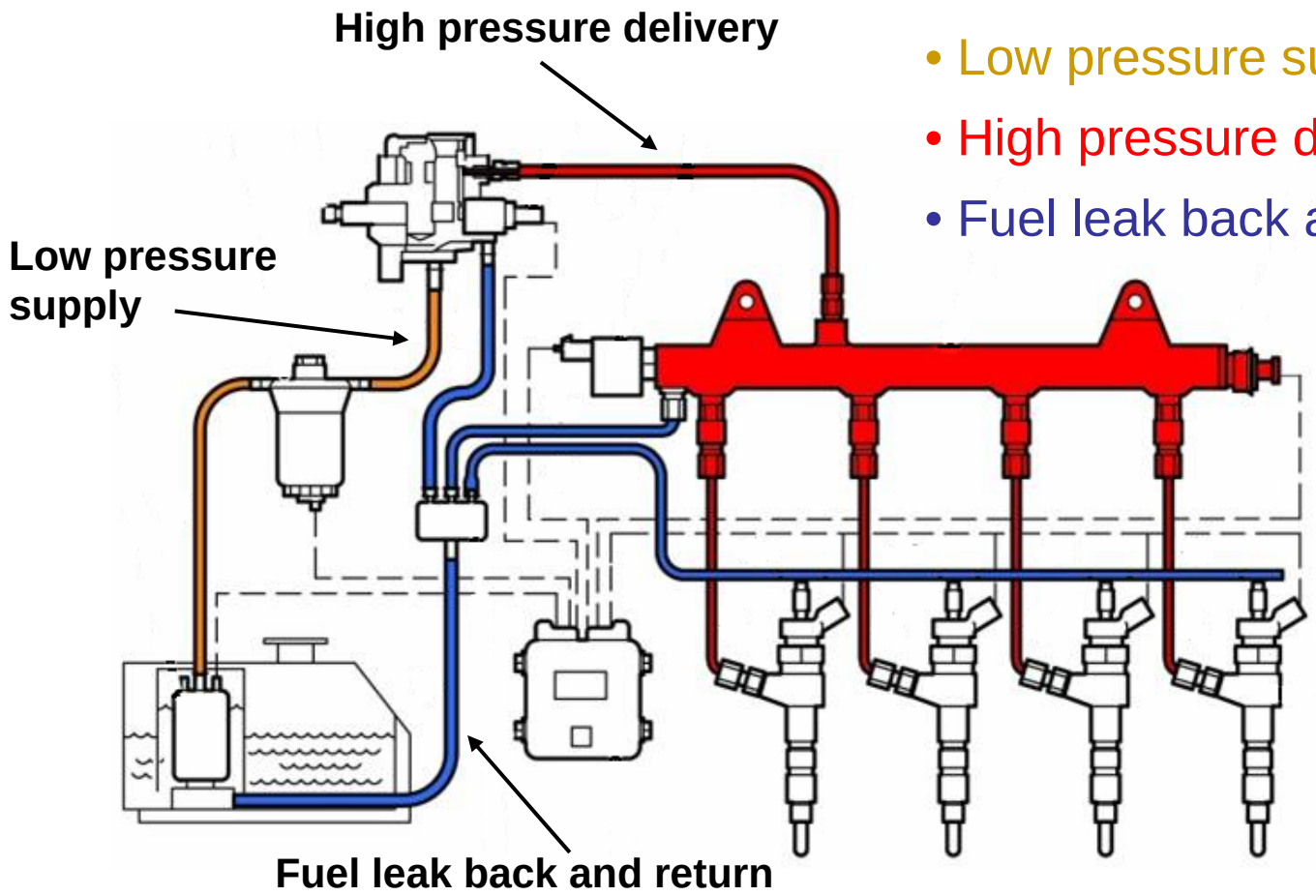


**Denso ECD-U2P**

# Common Rail Diesel Fuel Systems

The fuel system can be divided into three basic circuits

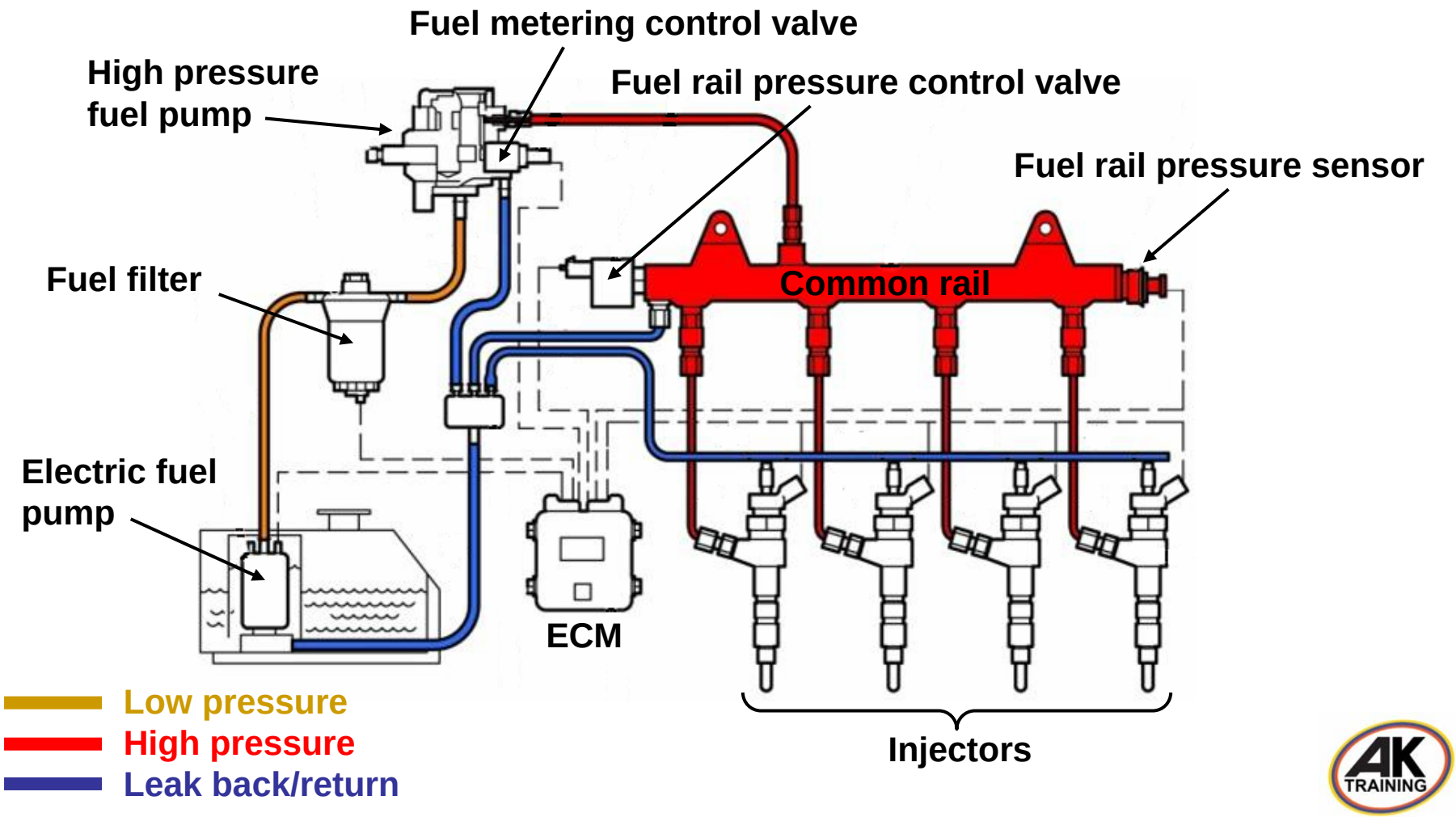
- Low pressure supply circuit
- High pressure delivery circuit
- Fuel leak back and return




Example: Bosch EDC16

# Common Rail Diesel Fuel Systems

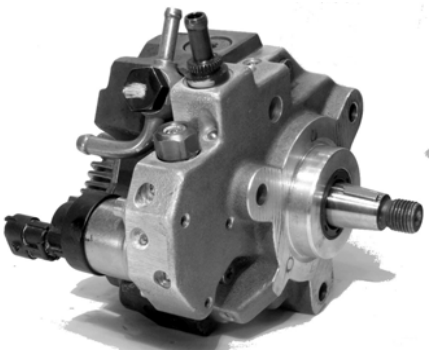
Components overview (example: Bosch EDC 16)



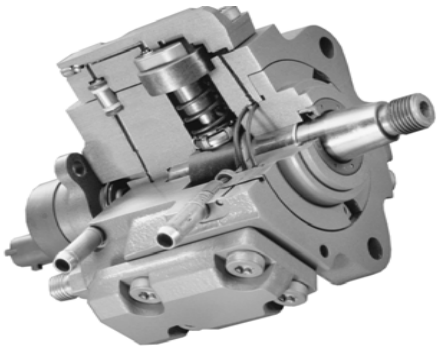
# Common Rail Diesel Fuel Systems

## High pressure fuel pump

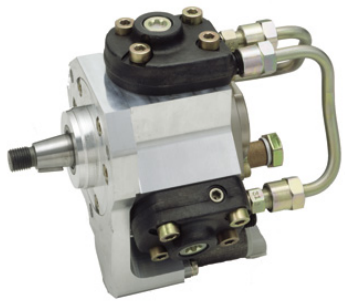
The High pressure pump is the interface between the low pressure and the high pressure side of the fuel system.



**Bosch CP3**



**Bosch CP1**



**Denso HP4**

**Denso HP3**

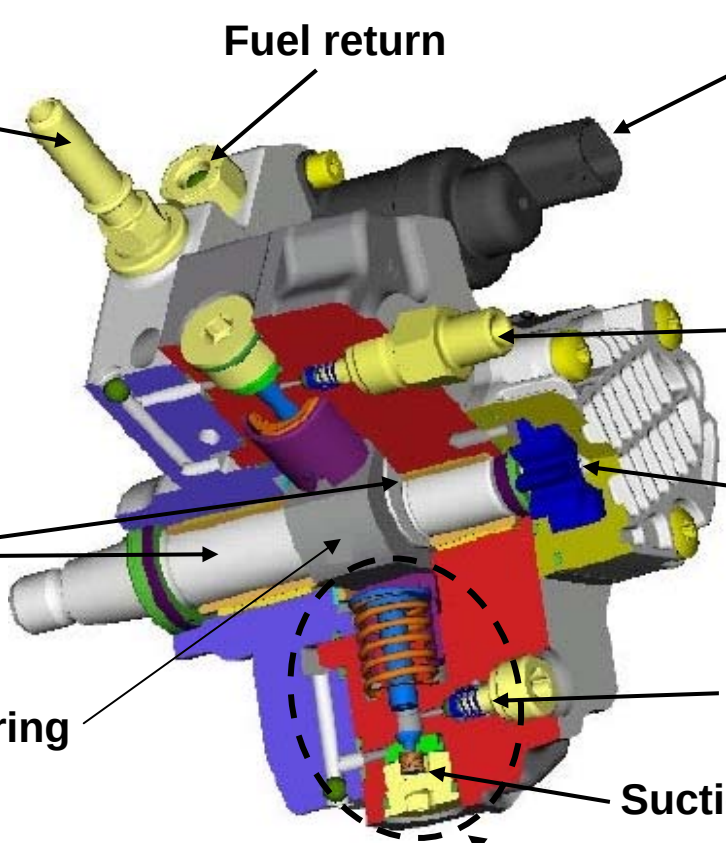
**Basic function:**

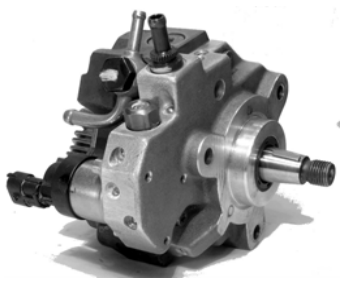
To ensure that enough fuel is delivered at sufficient pressure across the engine's entire operating range. This includes delivery of sufficient fuel for a rapid engine start and pressure increase in the rail.

# Common Rail Diesel Fuel Systems

High pressure fuel pump

**Example:**
**Bosch CP3**

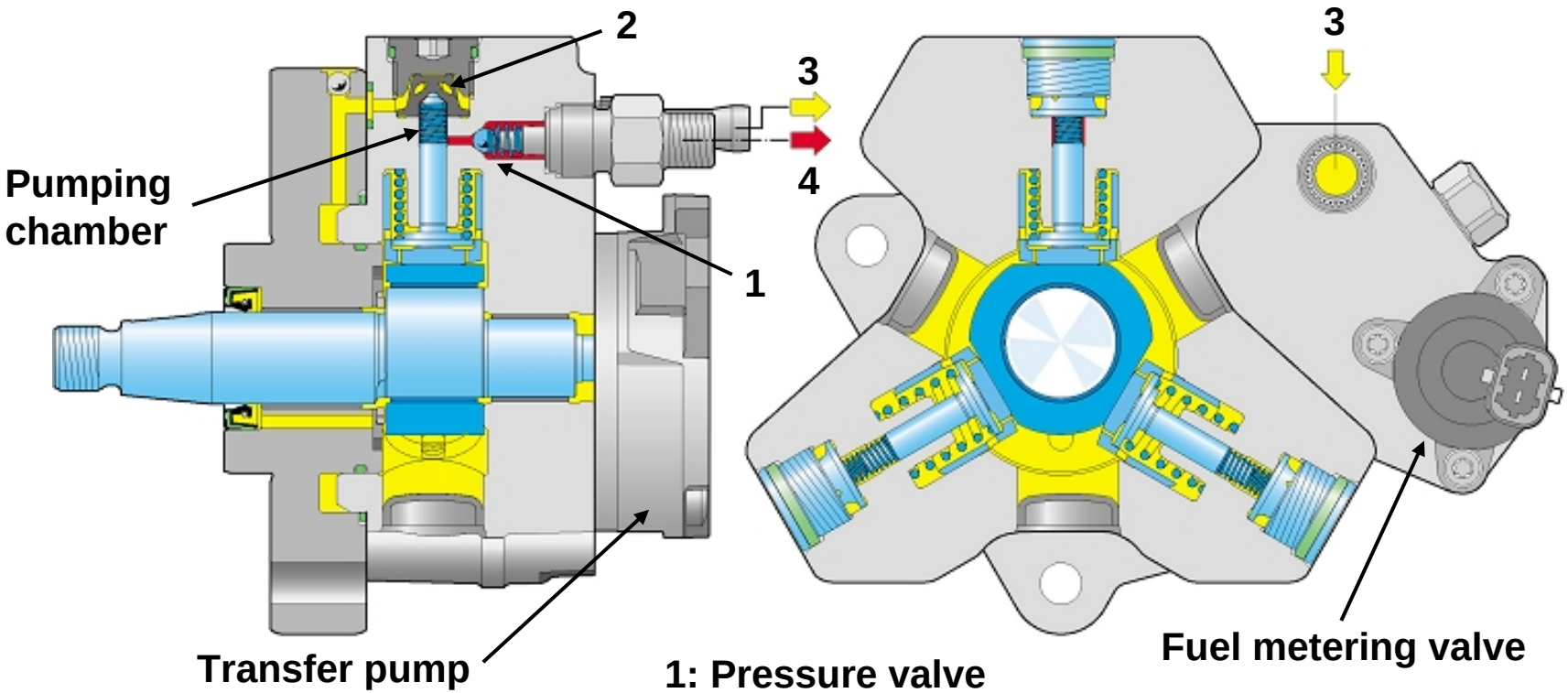


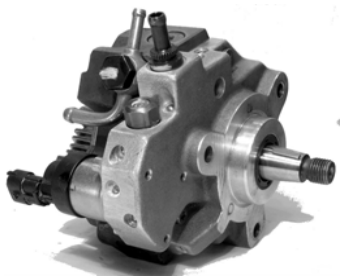



The pump has several pumping chambers

# Common Rail Diesel Fuel Systems

## High pressure fuel pump



1: Pressure valve

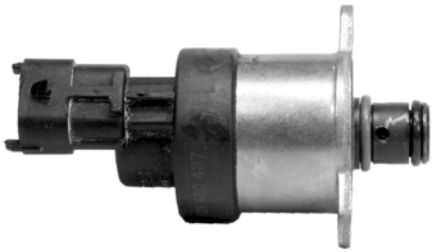
2: Suction valve

3: Low pressure (yellow)

4: High pressure (red)

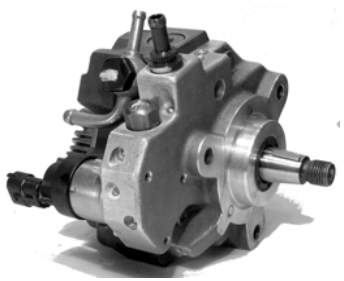
# Common Rail Diesel Fuel Systems

High pressure fuel pump



**Fuel metering valve**

**Transfer pump**

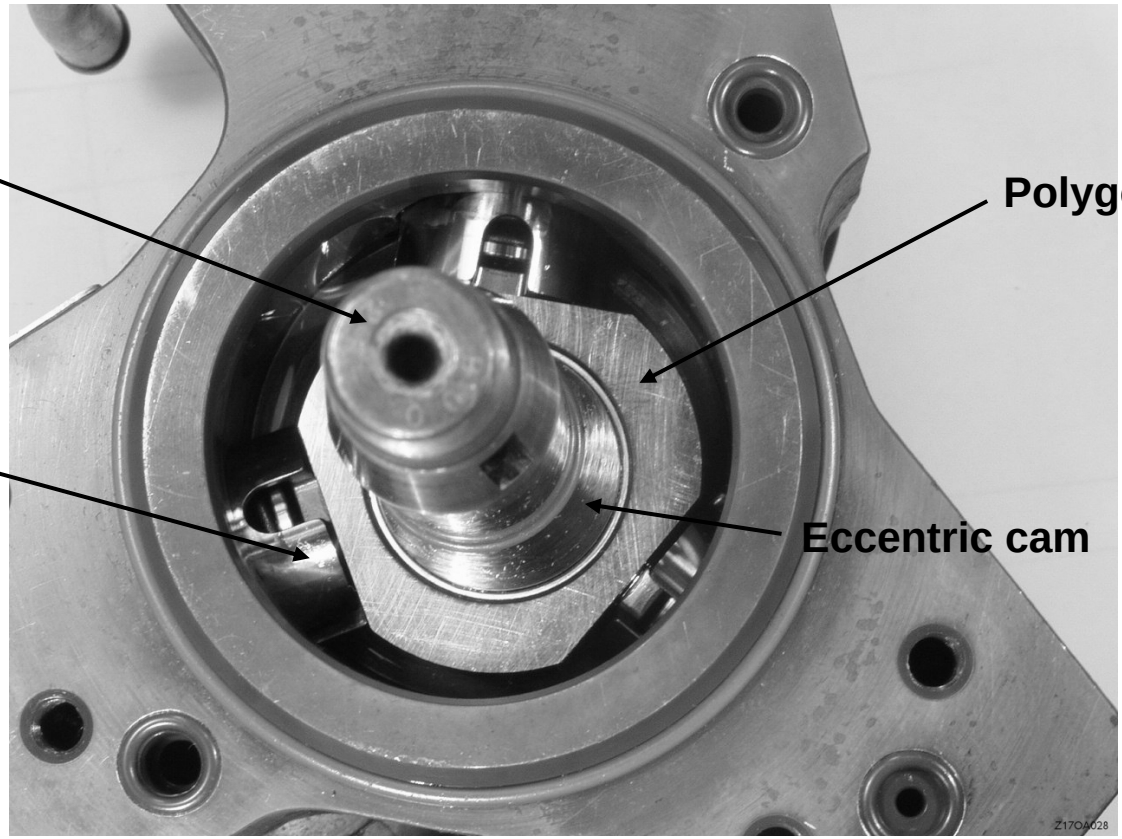


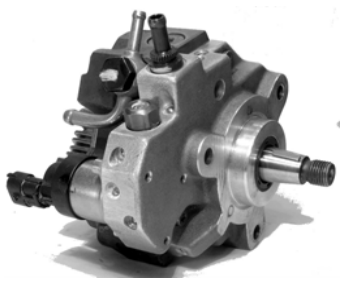
**Transfer pump supplies fuel from the fuel tank to the pumping chambers of the high pressure pump.**

**Fuel metering valve regulates the fuel intake volume to the pumping chambers of the high pressure pump.**

# Common Rail Diesel Fuel Systems

High pressure fuel pump

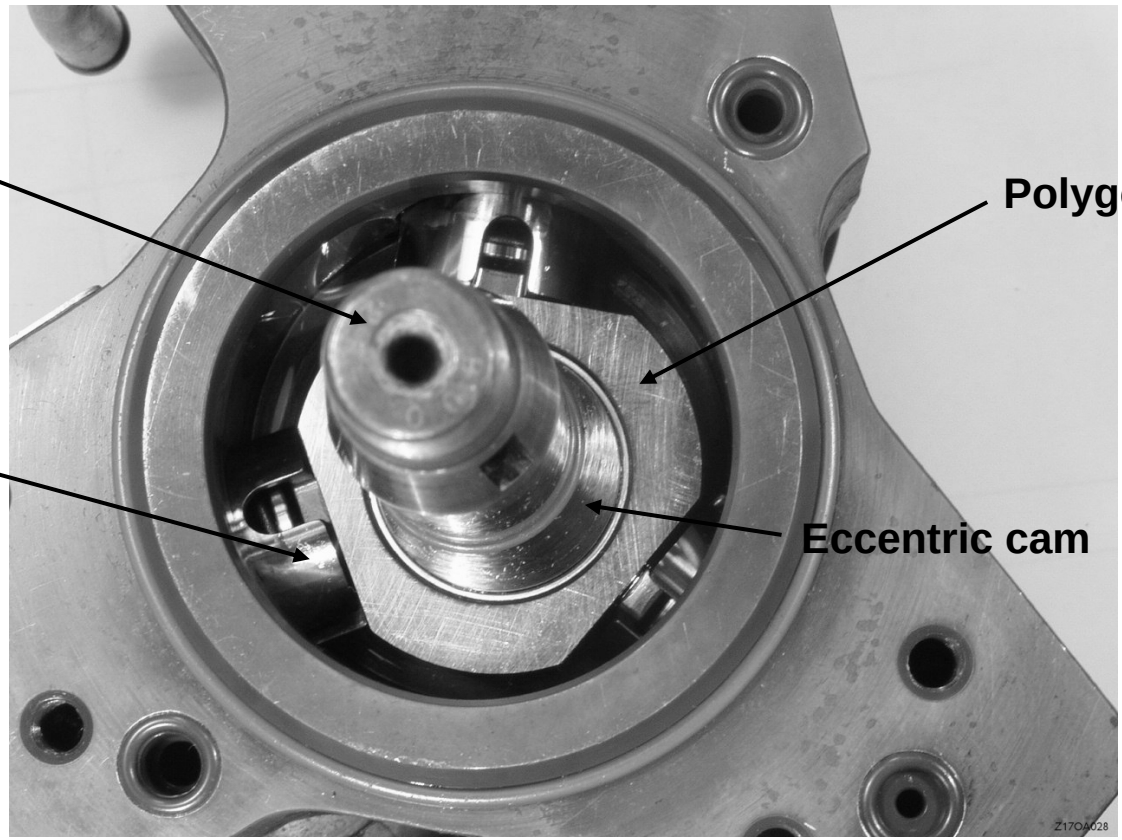


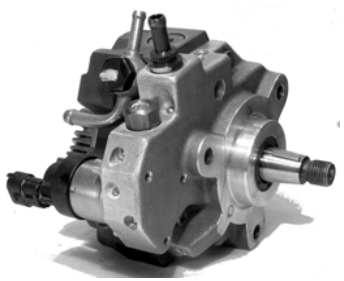



**3 pumping pistons are operated by a polygon ring on an eccentric cam on the pump shaft.**

# Common Rail Diesel Fuel Systems

High pressure fuel pump

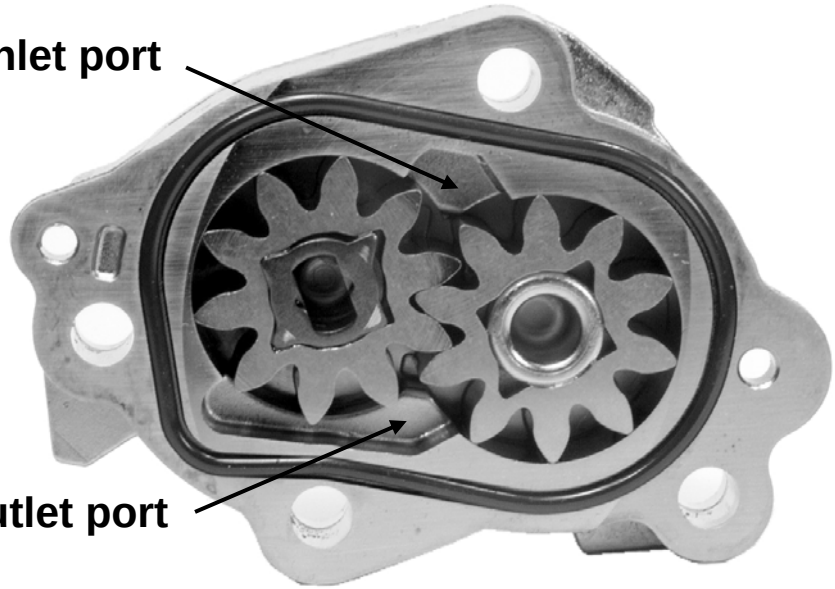


**As the pump rotates, the polygon ring moves in a circular motion to operate the pump pistons.**

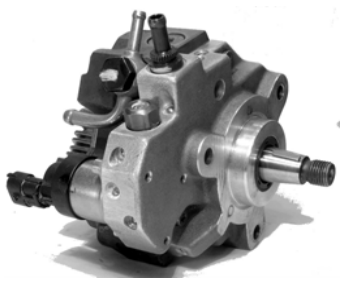
# Common Rail Diesel Fuel Systems

Transfer pump




**Gear type (Bosch CP3)**

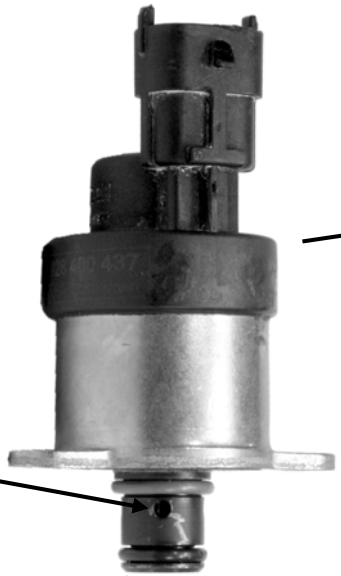

**Trochoidal type (Denso HP3)**



An electric pre supply pump in fuel tank may be used instead of a transfer pump. Some systems may use a combination of electric pump and transfer pump.

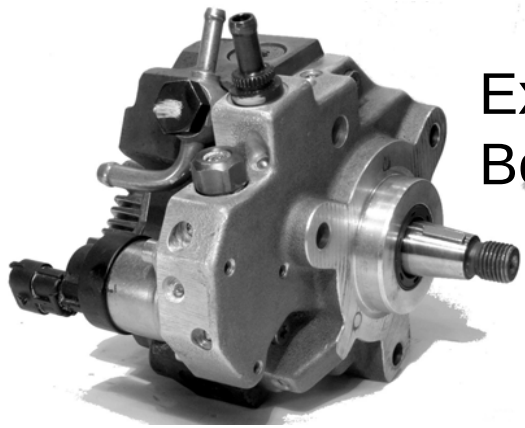
# Common Rail Diesel Fuel Systems

Fuel metering control valve



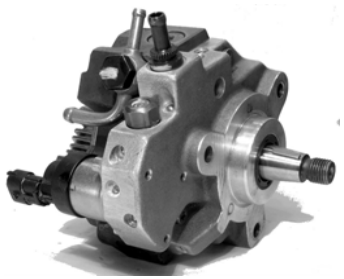
Fuel inlet

Fuel outlet



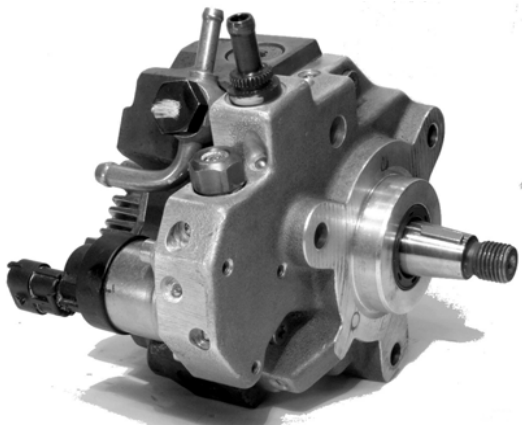
Example:
Bosch CP3

- Located at back of high pressure pump.
- Controls the fuel intake volume to the pump.
- Receives battery voltage supply from engine ECM.
- Energized by ECM via negatively triggered PWM.
- Operating frequency: approximately 180Hz.



# Common Rail Diesel Fuel Systems

Fuel metering control valve



**Fuel inlet**

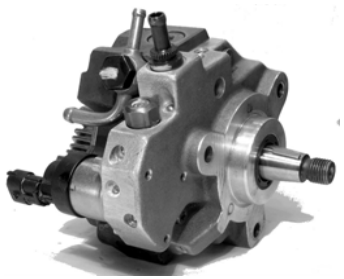
**Fuel outlet**

When solenoid de energized, valve is open

= **LOW** fuel volume intake to pump.

When solenoid energized, valve is closed

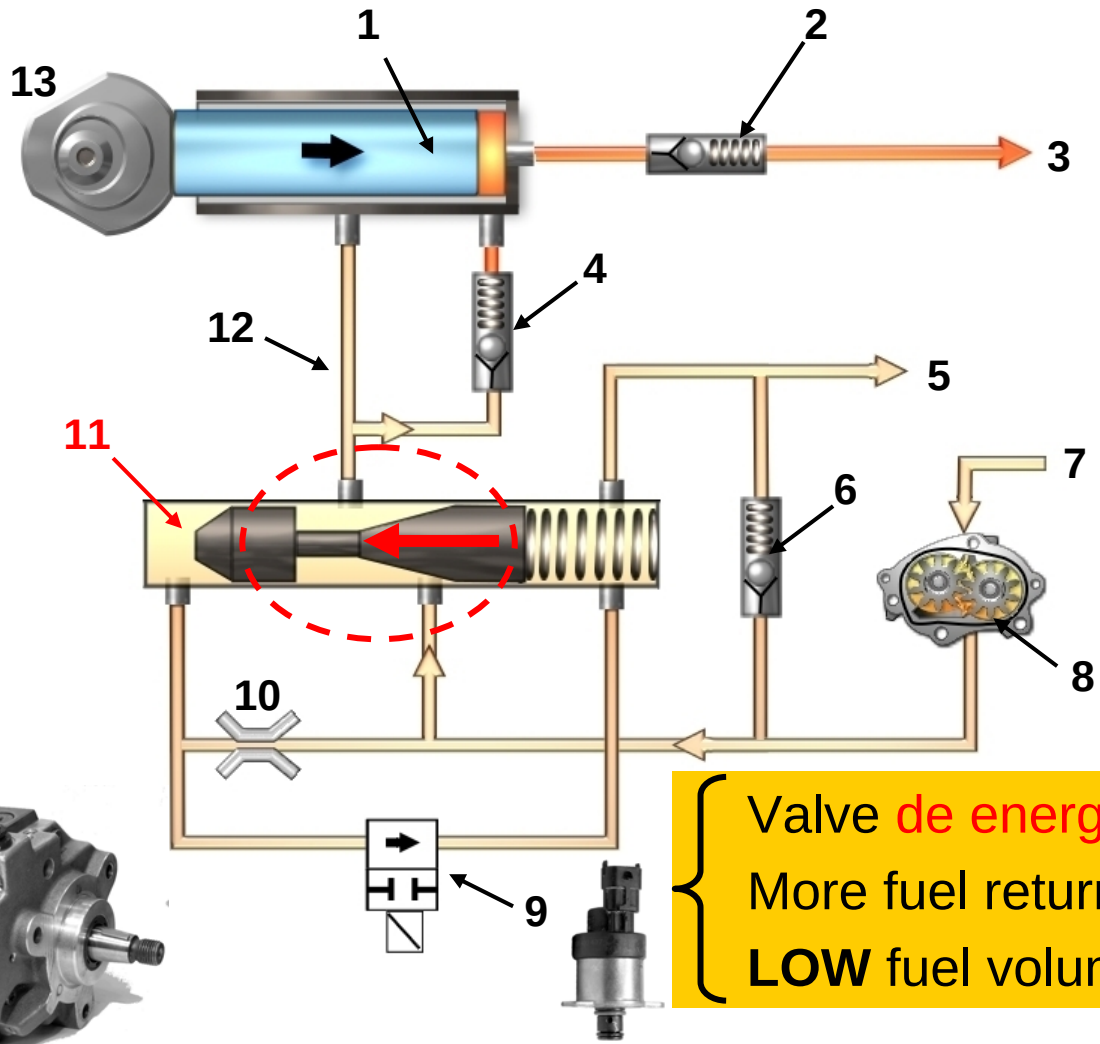
= **HIGH** fuel volume intake to pump.



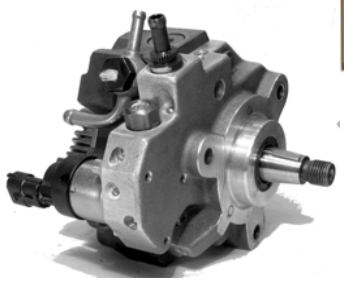
The fuel volume intake is controlled as follows.....

# Common Rail Diesel Fuel Systems

## Fuel volume intake control




1 Pump piston
2 Pressure valve
3 to common rail
4 Suction valve
5 Return
6 Safety valve
7 Feed (from the tank)
8 Gear pump
9 Fuel metering control valve
10 Throttle bore
11 Control piston
12 Lubricating-oil bore
13 High-pressure pump



Valve de energized **OPEN**

More fuel returns to tank

**LOW** fuel volume to pump

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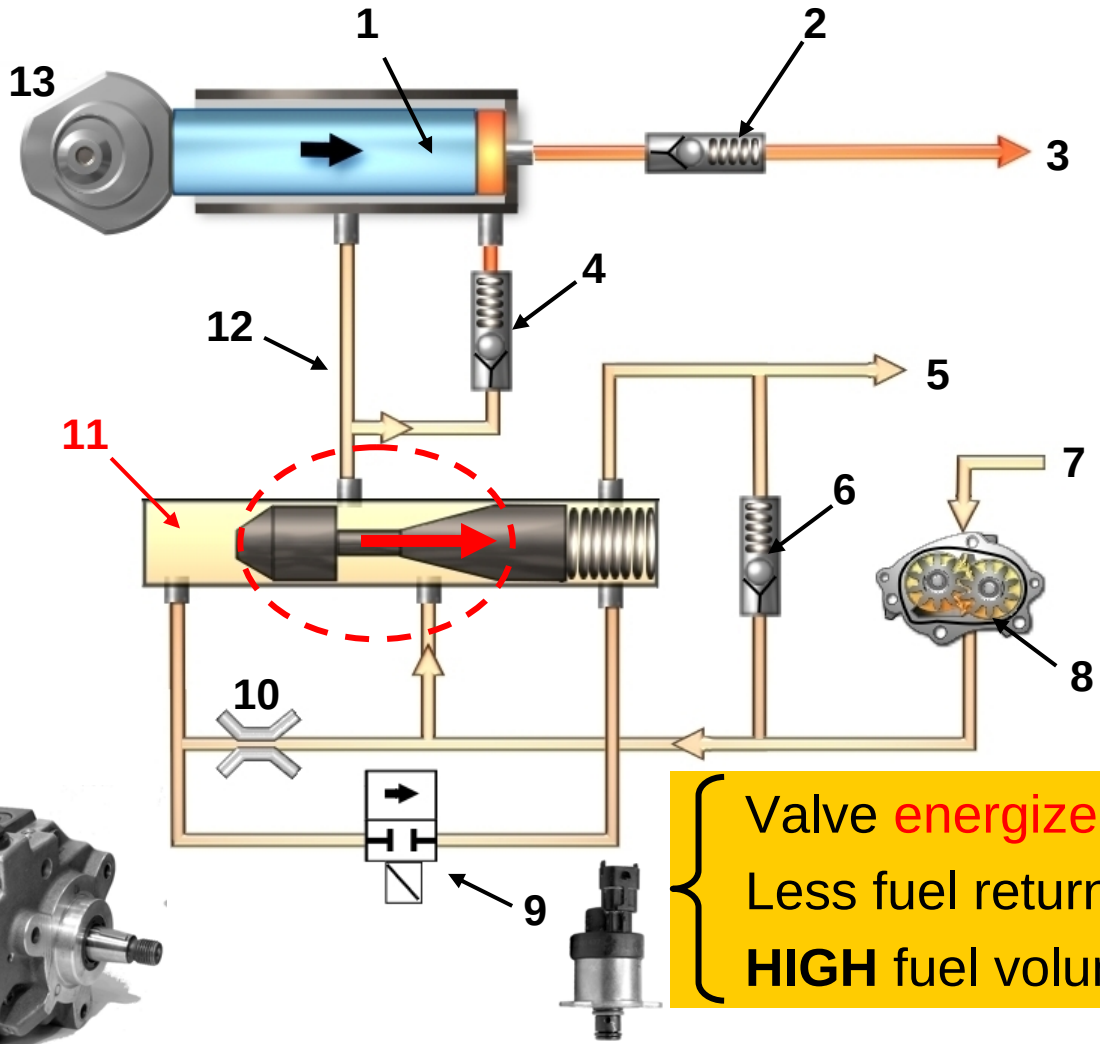
# Common Rail Diesel Fuel Systems

## Fuel volume intake control

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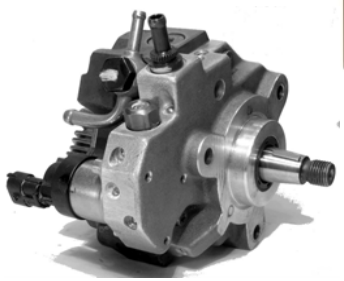

Valve energized **CLOSED**

Less fuel returns to tank

**HIGH** fuel volume to pump

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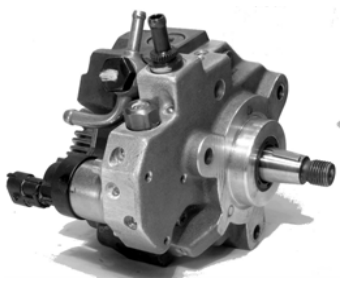
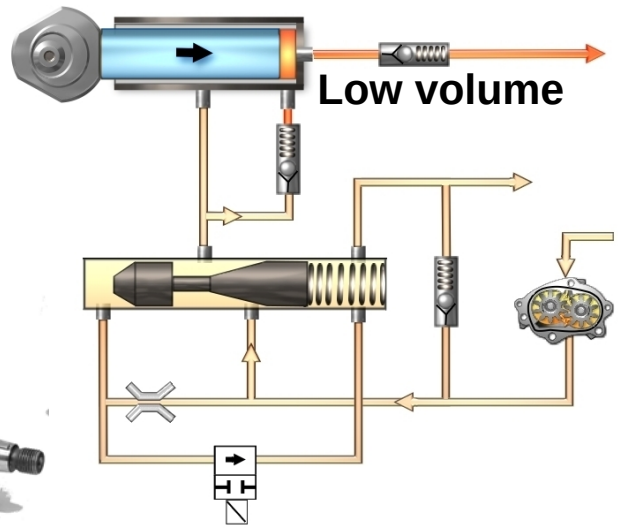
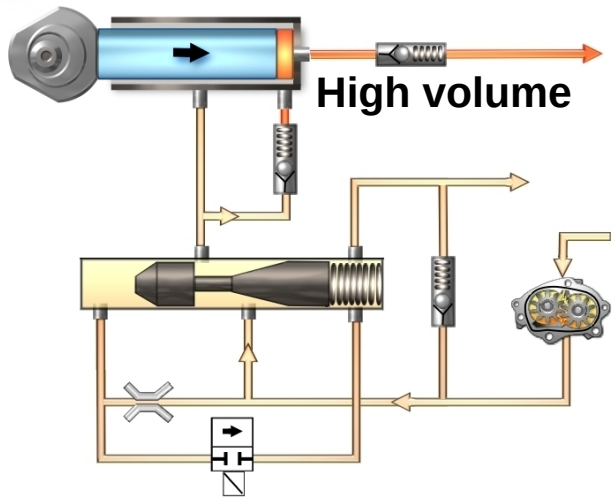
# Common Rail Diesel Fuel Systems

Advantages of fuel intake volume regulation:

- Only the required volume of fuel is supplied to the common rail from the high pressure pump.....
- Reduced fuel flow around system results in lower fuel return flow temperature.....
- Reduced parasitic load on engine from high pressure pump contributes towards further reductions in exhaust emissions.





# Common Rail Diesel Fuel Systems

Fuel metering control valve failure symptoms and diagnosis

Solenoid circuit monitored by engine ECM.
If an open or short circuit is detected:

**Engine stops or will not start.**
**DTC stored and MIL illuminated.**

Mechanical failure of the metering control valve does not necessarily prevent the engine from starting.

Mechanical faults can cause DTC's relating to positive or negative rail pressure deviations.

# Common Rail Diesel Fuel Systems

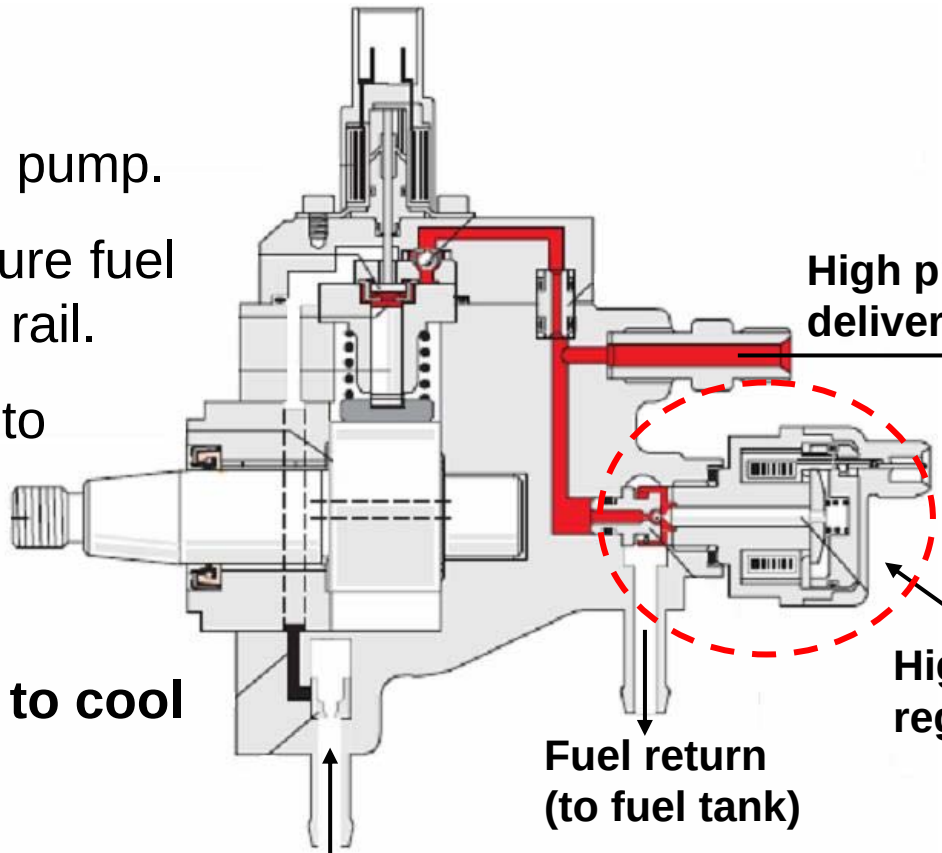
## High pressure regulator valve

System variant.

Fitted to back of HP pump.

Controls high pressure fuel delivery to common rail.

Excess fuel returns to tank.



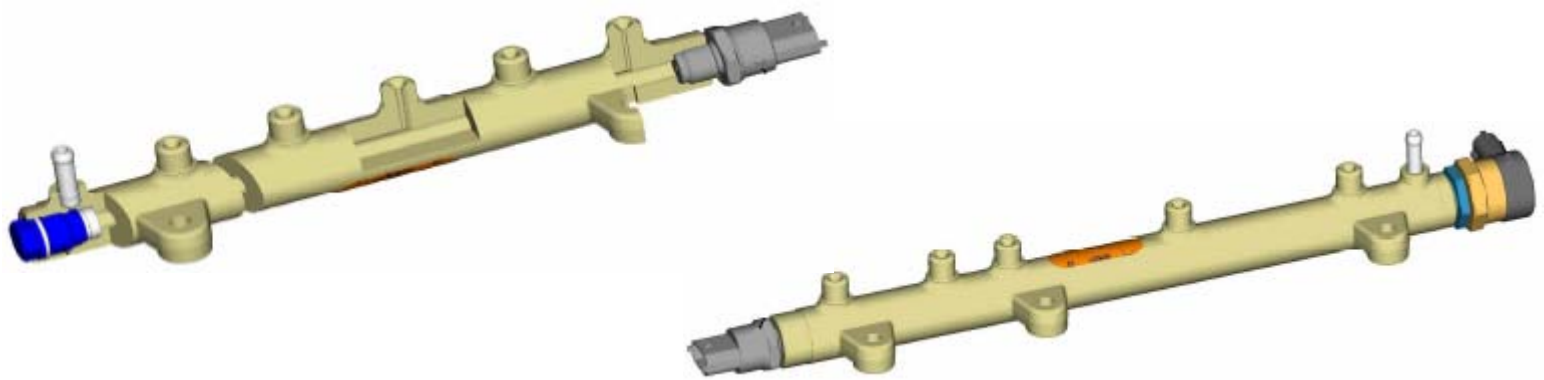

**Fuel cooler required to cool return fuel flow.**

# Common Rail Diesel Fuel Systems

High pressure accumulator (common rail)

Fuel is supplied to the common rail at high pressure from the high pressure pump.

The rail stores the fuel and distributes it to the individual injectors.



It also damps pressure vibrations caused by the high pressure pump and injection processes.

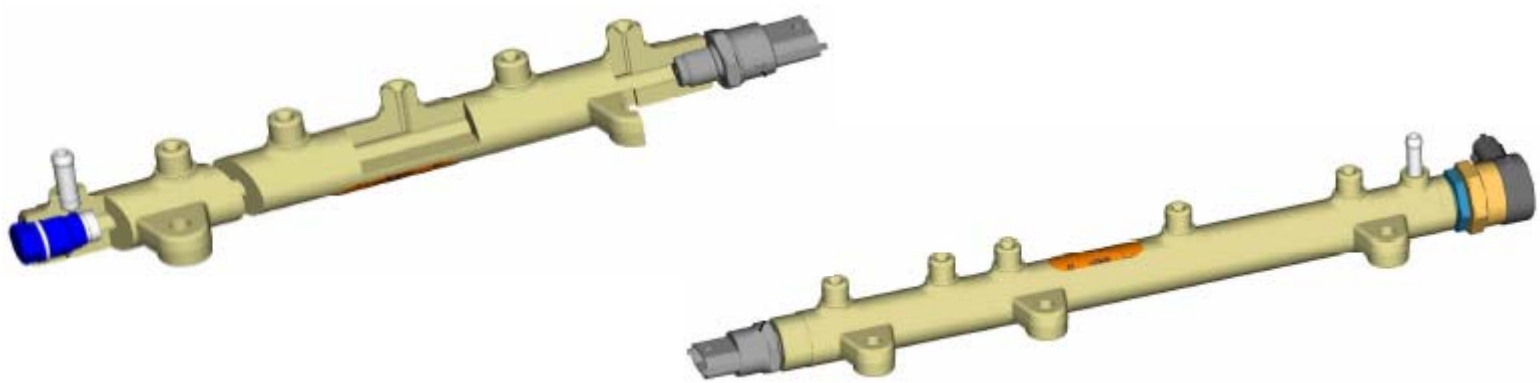
Typical volume of fuel held in common rail: 16 – 20cm$^3$.

# Common Rail Diesel Fuel Systems

High pressure accumulator (common rail)

Typical fuel rail pressure with engine **idling** and at running temperature:

approximately between 300 – 400 Bar (4410 – 5880 psi)



Typical maximum possible fuel rail pressure:

approximately between 1600 – 2000 Bar (23520 – 28400 psi)

# Common Rail Diesel Fuel Systems

High pressure accumulator (common rail)

Typical fuel rail pressure with engine **idling** and at running temperature:

approximately between 300 – 400 Bar (4410 – 5880 psi)

## Health and safety

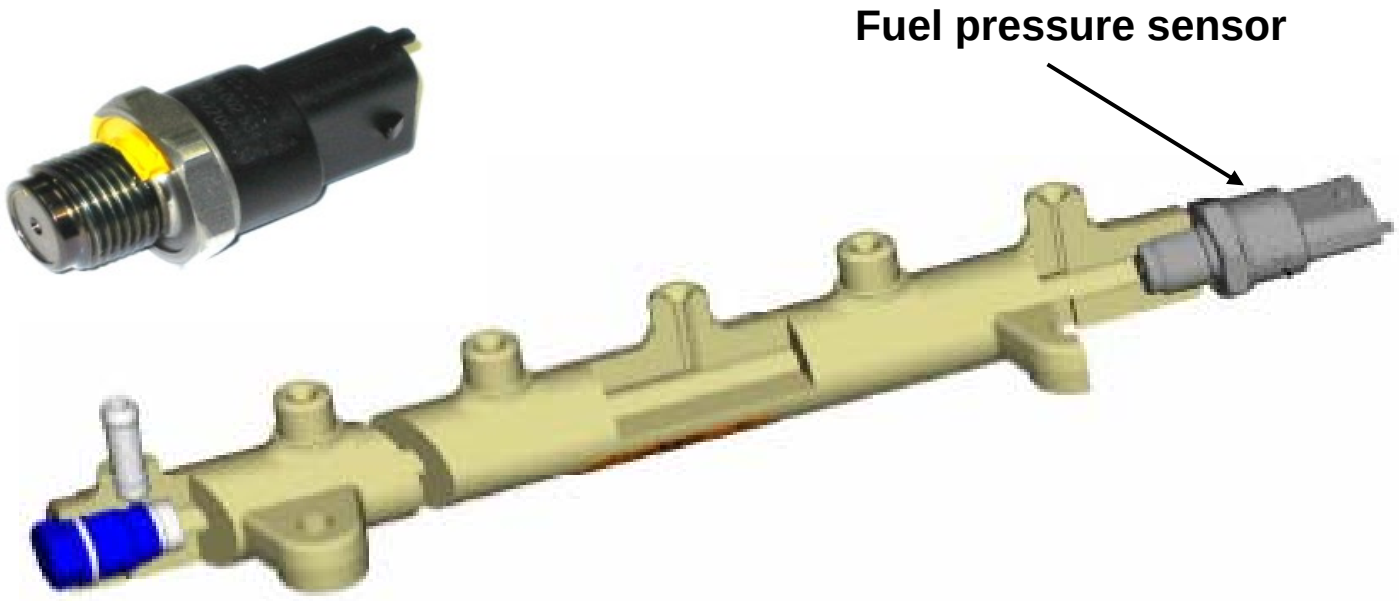
**Due to the extremely high working fuel pressures in the common rail fuel system, NEVER slacken fuel or injector pipes or try to disconnect components of the fuel system whilst the engine is running and high pressure is present in the system!**

Typical maximum possible fuel rail pressure:

approximately between 1600 – 2000 Bar (23520 – 28400 psi)

# Common Rail Diesel Fuel Systems

Fuel rail pressure sensor




A fuel rail pressure sensor is located on the fuel rail.

# Common Rail Diesel Fuel Systems

## Fuel rail pressure sensor

Monitors the fuel pressure in the common rail.

Typically a piezo resistive type sensor.

Three wires:

- 5 Volt supply from engine ECM.
- Sensor ground via engine ECM.
- Linear signal voltage output to ECM.

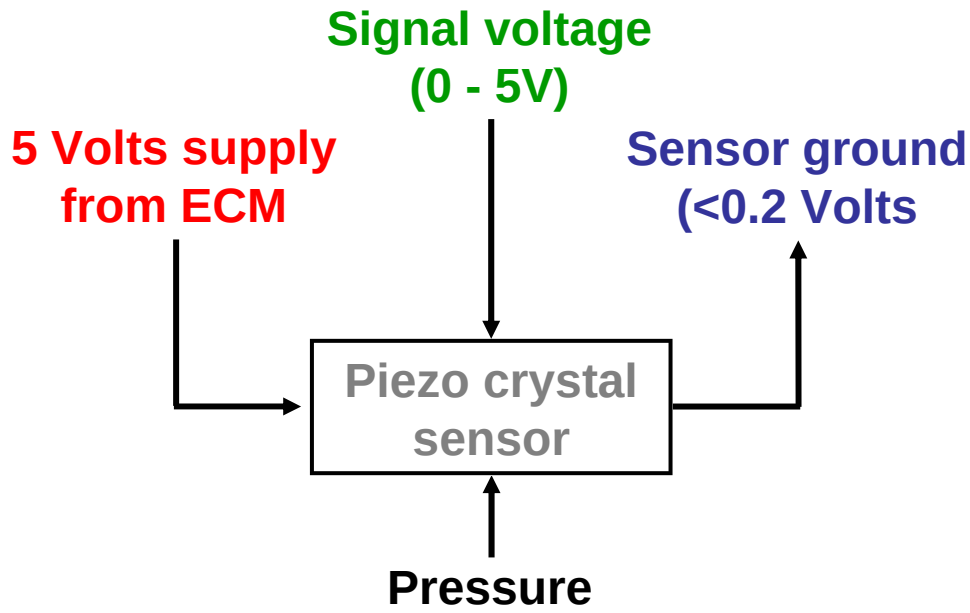
## Signal utilization:

To enable the engine ECM to determine the fuel rail pressure.....

Used by the ECM as part of the calculation for the % duty cycle applied to the rail pressure control solenoid and fuel metering solenoid.

# Common Rail Diesel Fuel Systems

Fuel rail pressure sensor

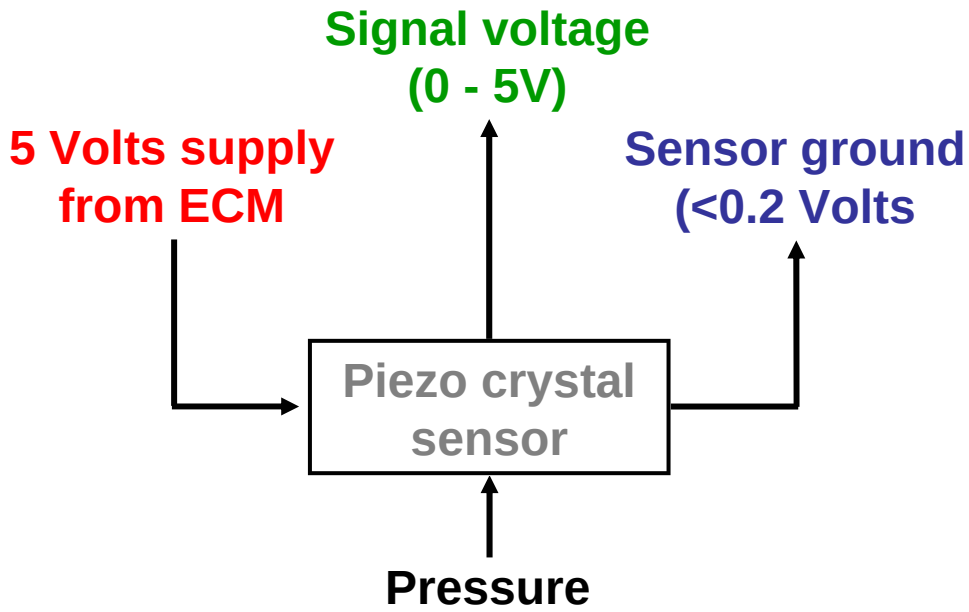



The engine ECM applies a stabilized 5 Volts supply to the signal wire of the fuel pressure sensor.....

The resistive value of the sensor creates a change in the voltage on the signal wire relative to the fuel rail pressure.

# Common Rail Diesel Fuel Systems

Fuel rail pressure sensor




Typical signal voltages from rail pressure sensor:

Engine stationary: approximately 0.5 volts.

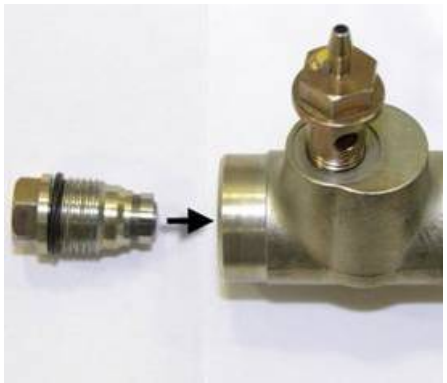
Engine idling: approximately 1.32 volts.

Snap acceleration: approximately 3.77 volts +

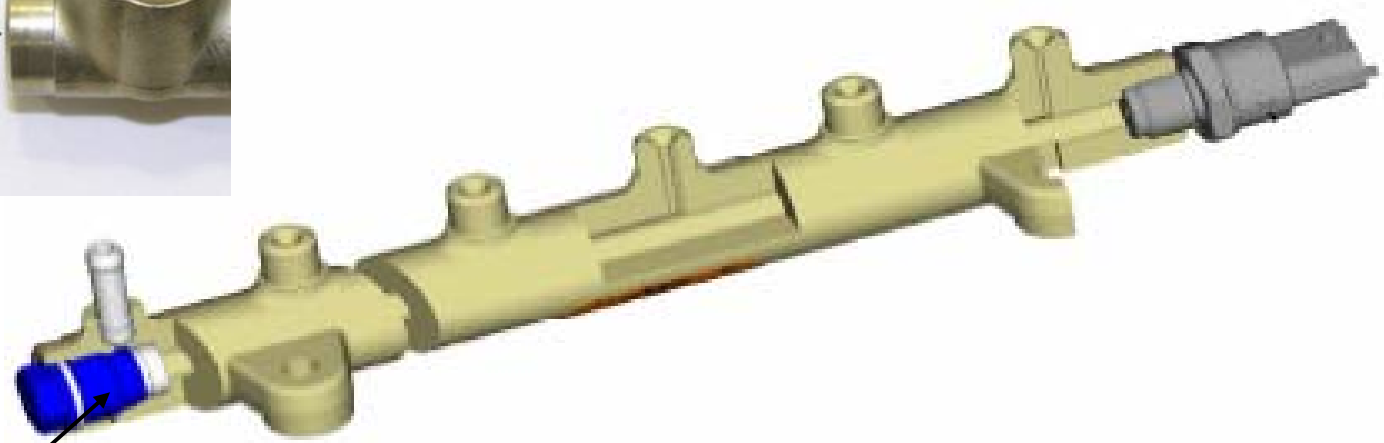
(Example figures Bosch EDC16).

# Common Rail Diesel Fuel Systems

## Rail pressure limiter valve



A mechanical pressure limiter valve is fitted to some systems. It is located at the end of the fuel rail.

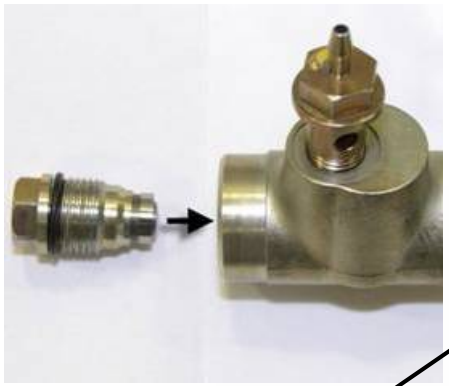


**Rail pressure limiter valve (mechanical)**

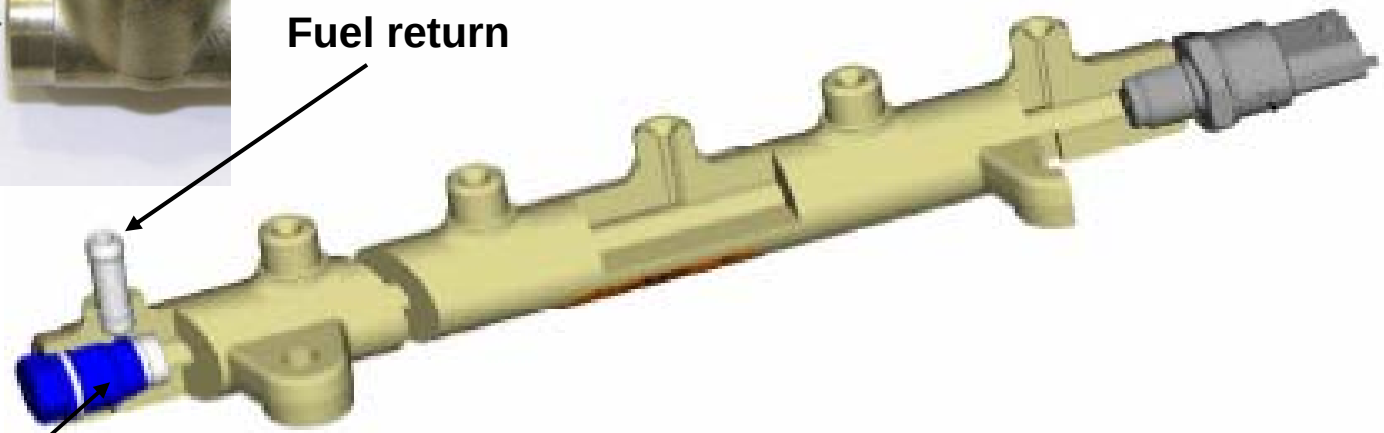
Its function is to relieve rail pressure if abnormally high system pressure is generated.

# Common Rail Diesel Fuel Systems

## Rail pressure limiter valve



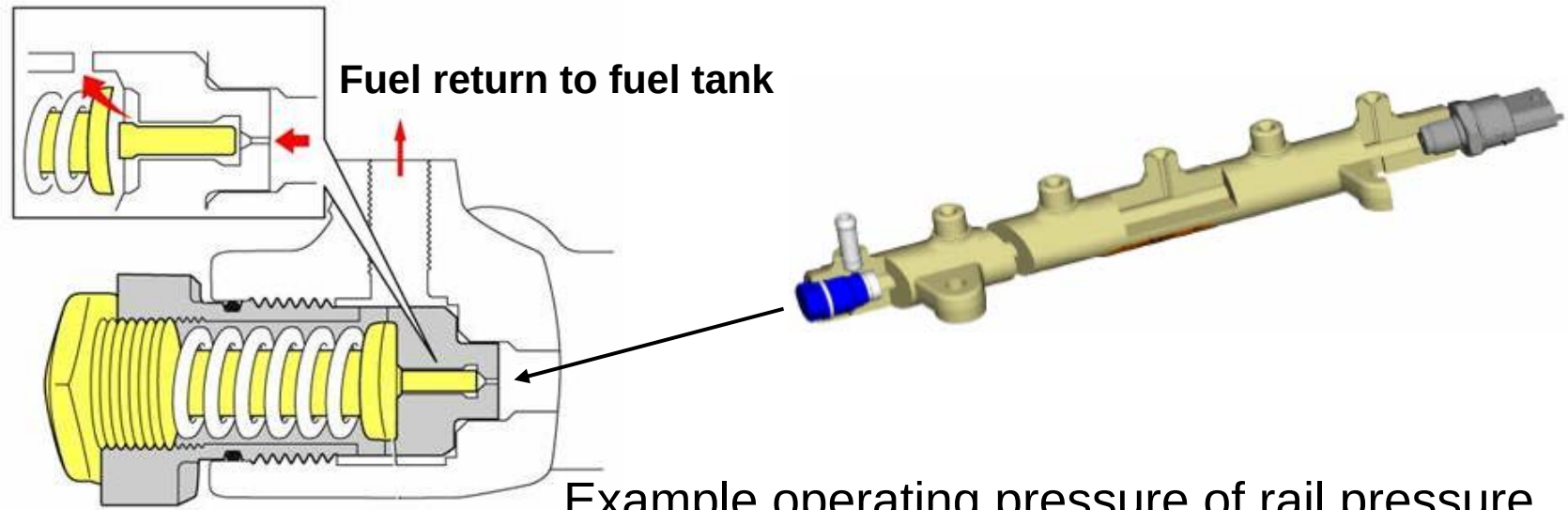
If excessive fuel pressure is generated, the valve opens a fuel return port.




Excess fuel is relieved back to the fuel tank.

# Common Rail Diesel Fuel Systems

Rail pressure limiter valve



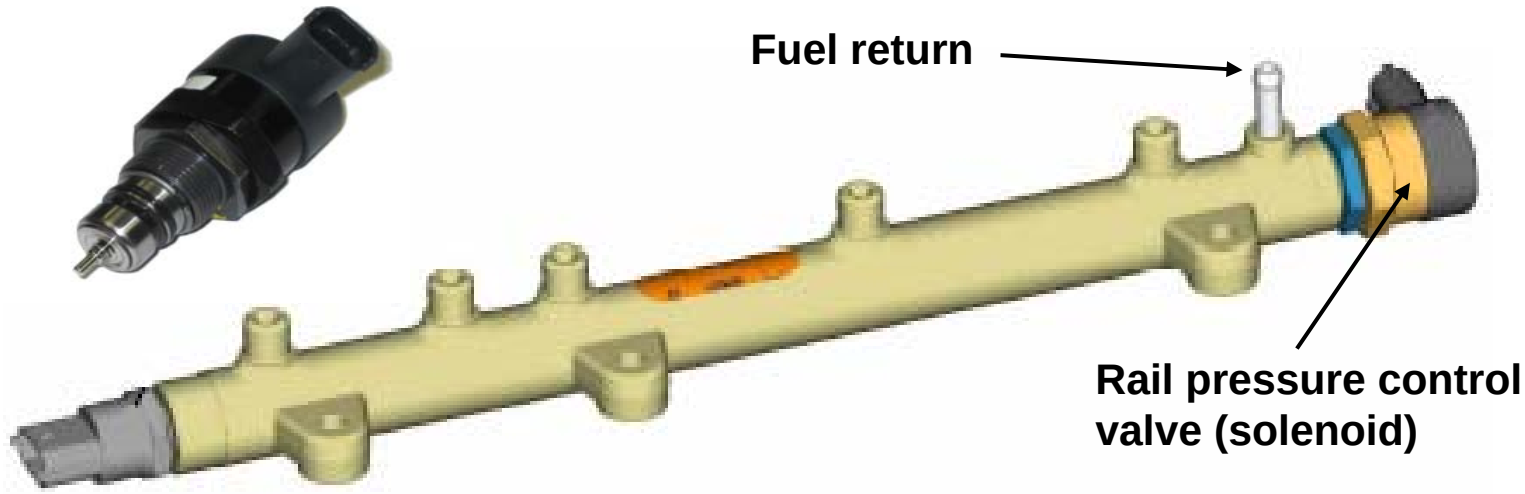

Example operating pressure of rail pressure limiter valve (Denso HP3 system):

valve opens at 230 MPa (2300 Bar)
valve closes at 50 MPa (500 Bar)

# Common Rail Diesel Fuel Systems

## Fuel rail pressure control valve solenoid

A rail pressure control valve solenoid is fitted to the common rail on some systems.




The valve controls fuel pressure by opening and closing a return port in the rail.

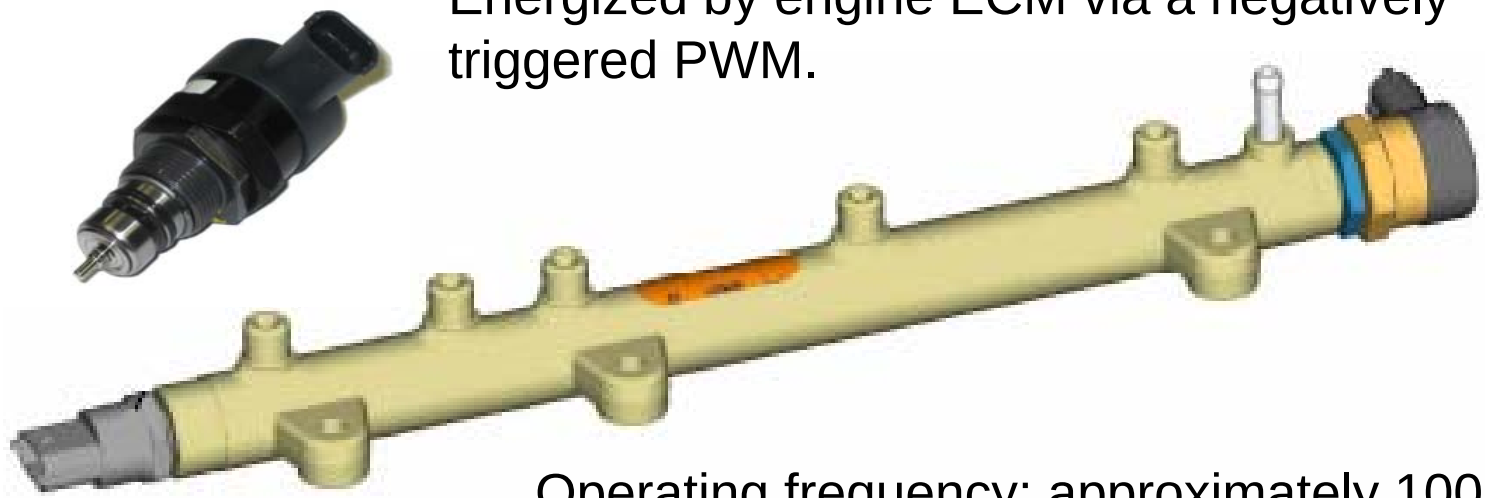
Excess fuel returns to the fuel tank via the fuel return.

# Common Rail Diesel Fuel Systems

Rail pressure control valve solenoid

Receives battery voltage supply from engine ECM.

Energized by engine ECM via a negatively triggered PWM.



Operating frequency: approximately 1000Hz

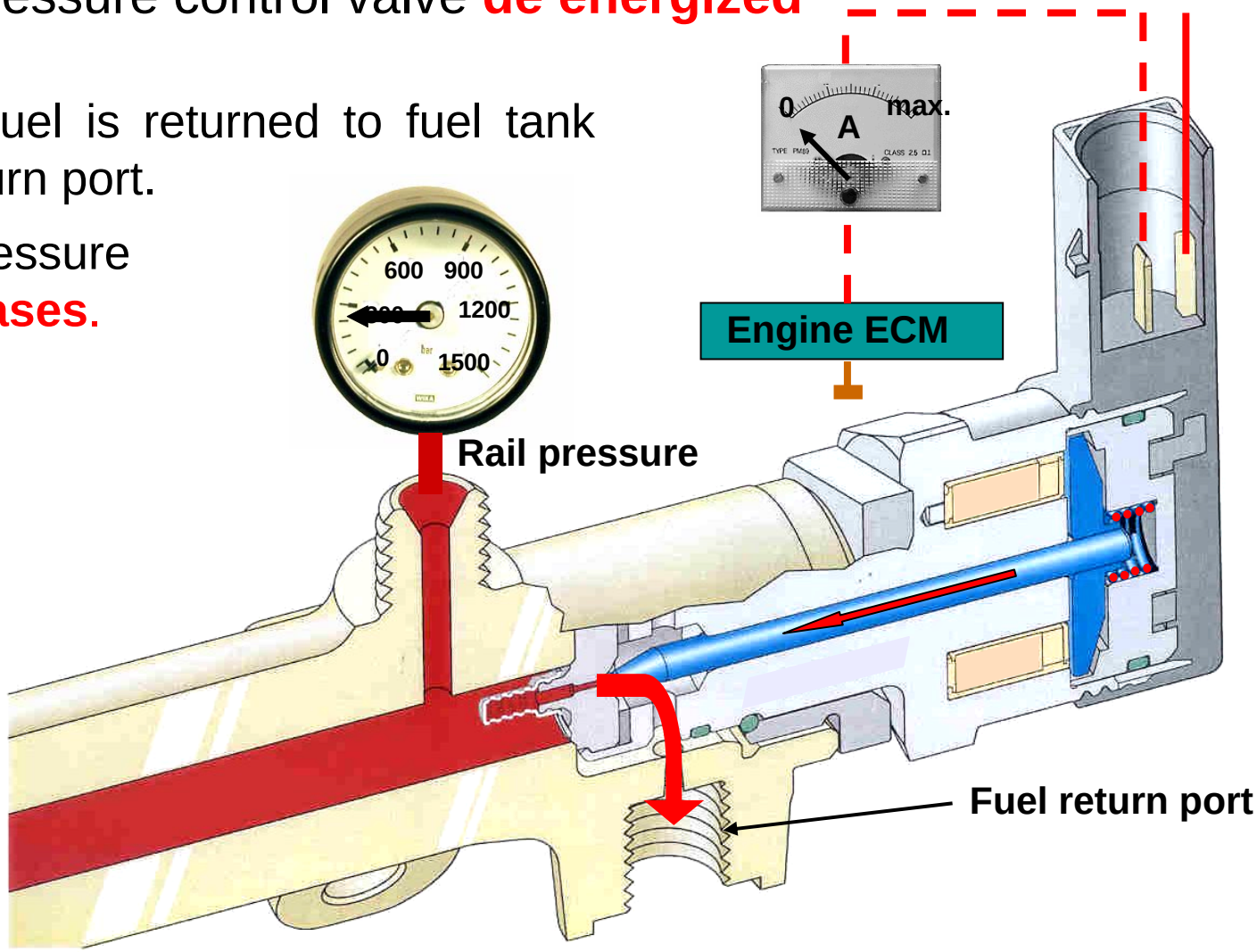
Used in conjunction with fuel metering solenoid, the rail pressure solenoid provides more accurate and faster control of pressure, particularly when reducing rail pressure during overrun.

# Common Rail Diesel Fuel Systems

Rail pressure control valve **de energized**

**More** fuel is returned to fuel tank via return port.

Rail pressure **Decreases**.

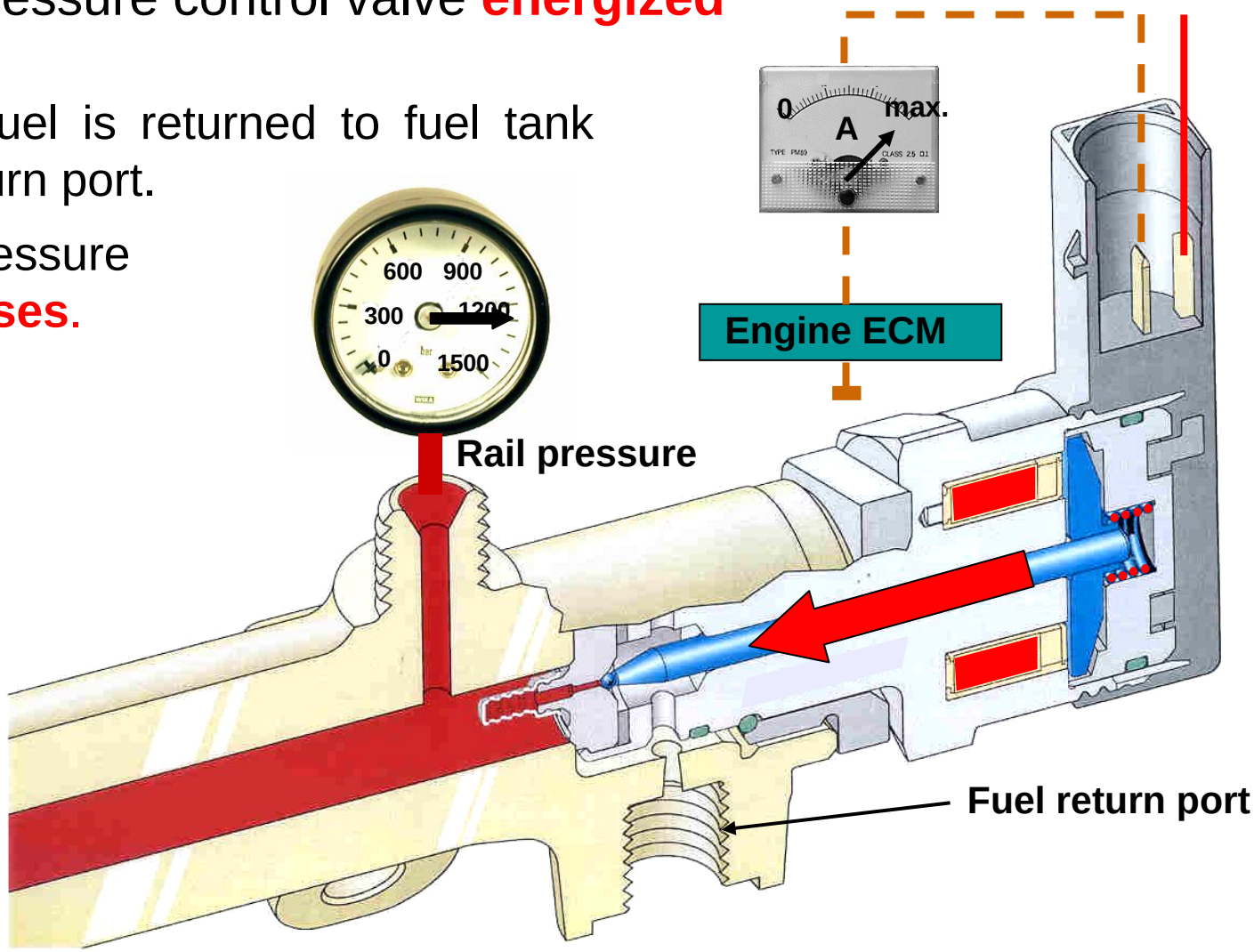


# Common Rail Diesel Fuel Systems

Rail pressure control valve **energized**

**Less** fuel is returned to fuel tank via return port.

Rail pressure **Increases**.



# Common Rail Diesel Fuel Systems

Rail pressure control valve failure symptoms and diagnosis

Most likely consequence:

**Engine stops or will not start.**

Solenoid circuit monitored by engine ECM.
Open or short circuit detected:

**DTC stored and MIL illuminated.**
(Engine stops or will not start).

Mechanical failure:

A minimum amount of fuel rail pressure is required to enable the engine to start.

Typical value:

approximately between 200 - 300 Bar

# Common Rail Diesel Fuel Systems

Rail pressure control valve failure symptoms and diagnosis

Most likely consequence:

**Engine stops or will not start.**

Solenoid circuit monitored by engine ECM.
Open or short circuit detected:

**DTC stored and MIL illuminated.**
(Engine stops or will not start).

Mechanical failure:

Valve stuck open = Low rail pressure.
Engine stops or will not start.

Valve stuck closed = High rail pressure.
Engine stops or will not start.

# Common Rail Diesel Fuel Systems

Testing rail pressure control valve

**Multimeter:**
Test internal resistance of valve solenoid winding.

Typical value: approximately 3.6 Ohms.

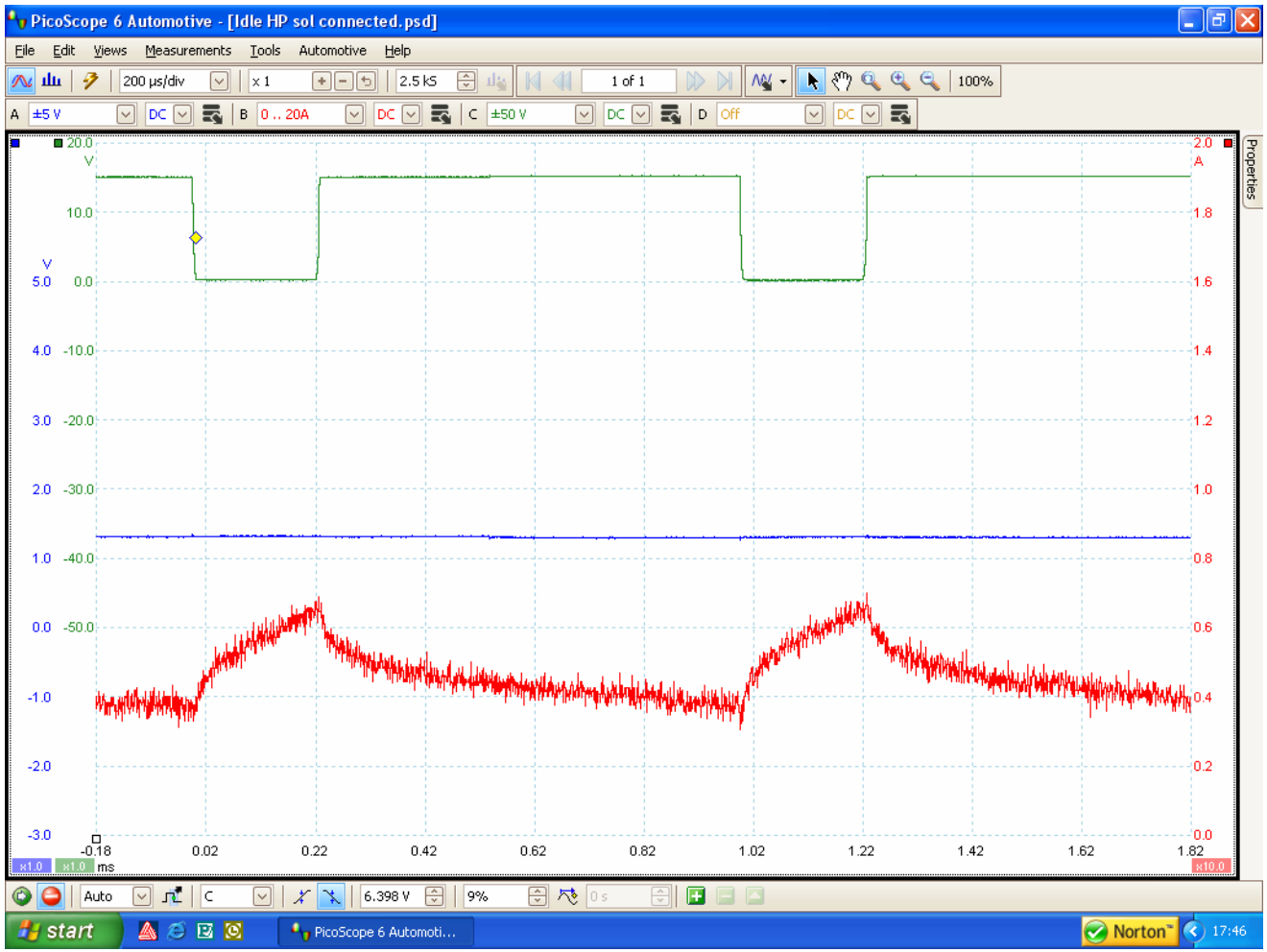
**Diagnostic scan tool:**
DTC’s and monitoring of rail pressure values.

**Oscilloscope:**
Test supply voltage and earth switching signal from engine ECM.

Test stability of waveform.

# Common Rail Diesel Fuel Systems

## Pressure control valve waveform: engine idling



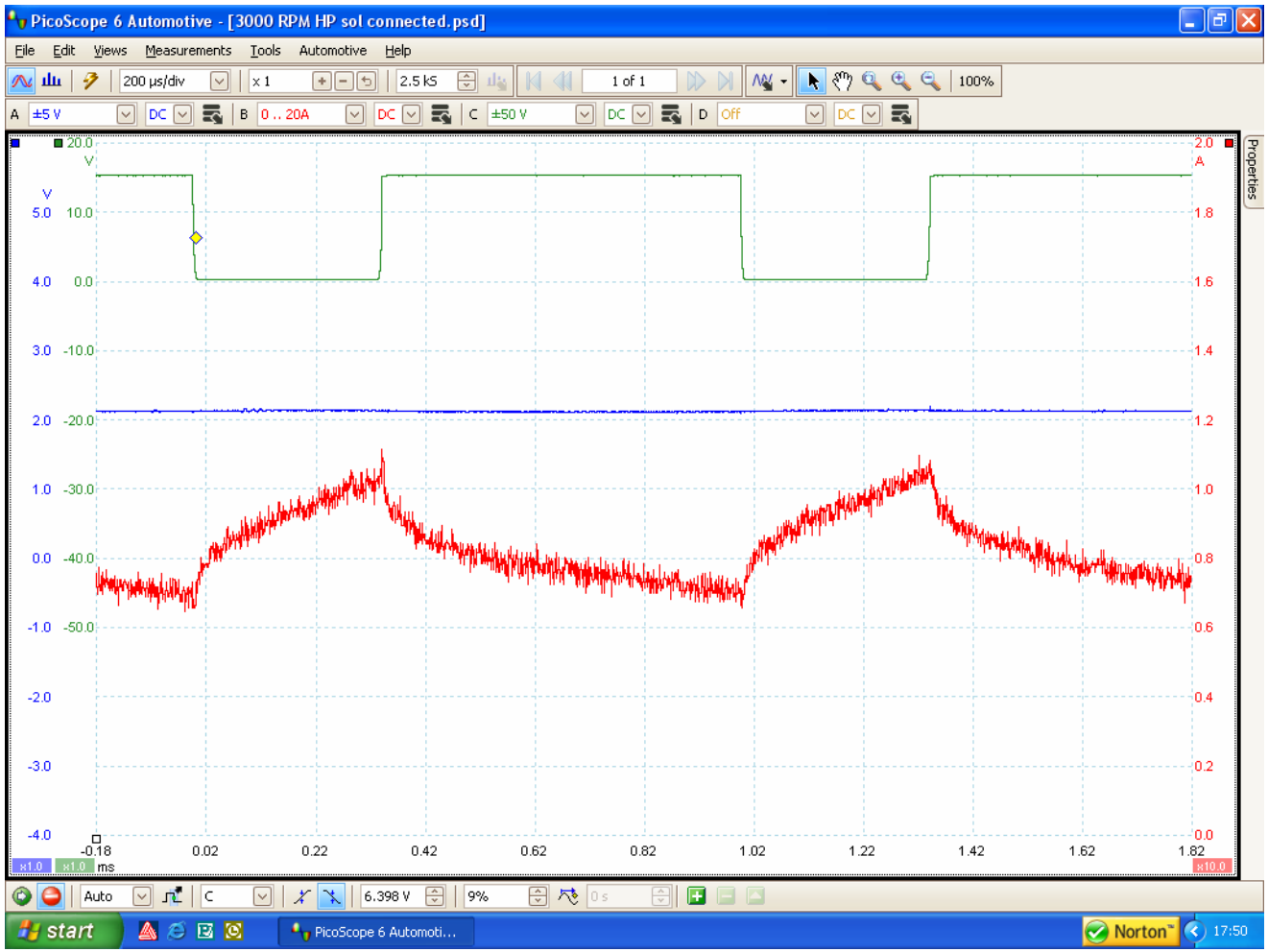

| | 1 | 2 | Δ |
|---|---|---|---|
| □ | -6.0 µs | 225.0 µs | 231.0 µs |
| ■ | 1.32 V | –.– | –.– |
| ■ | 664.0 x10^-3 A | –.– | –.– |

**Green = % duty cycle**
**Blue = rail pressure**
**Red = current draw**

AK TRAINING

# Common Rail Diesel Fuel Systems

## Pressure control valve waveform: snap acceleration



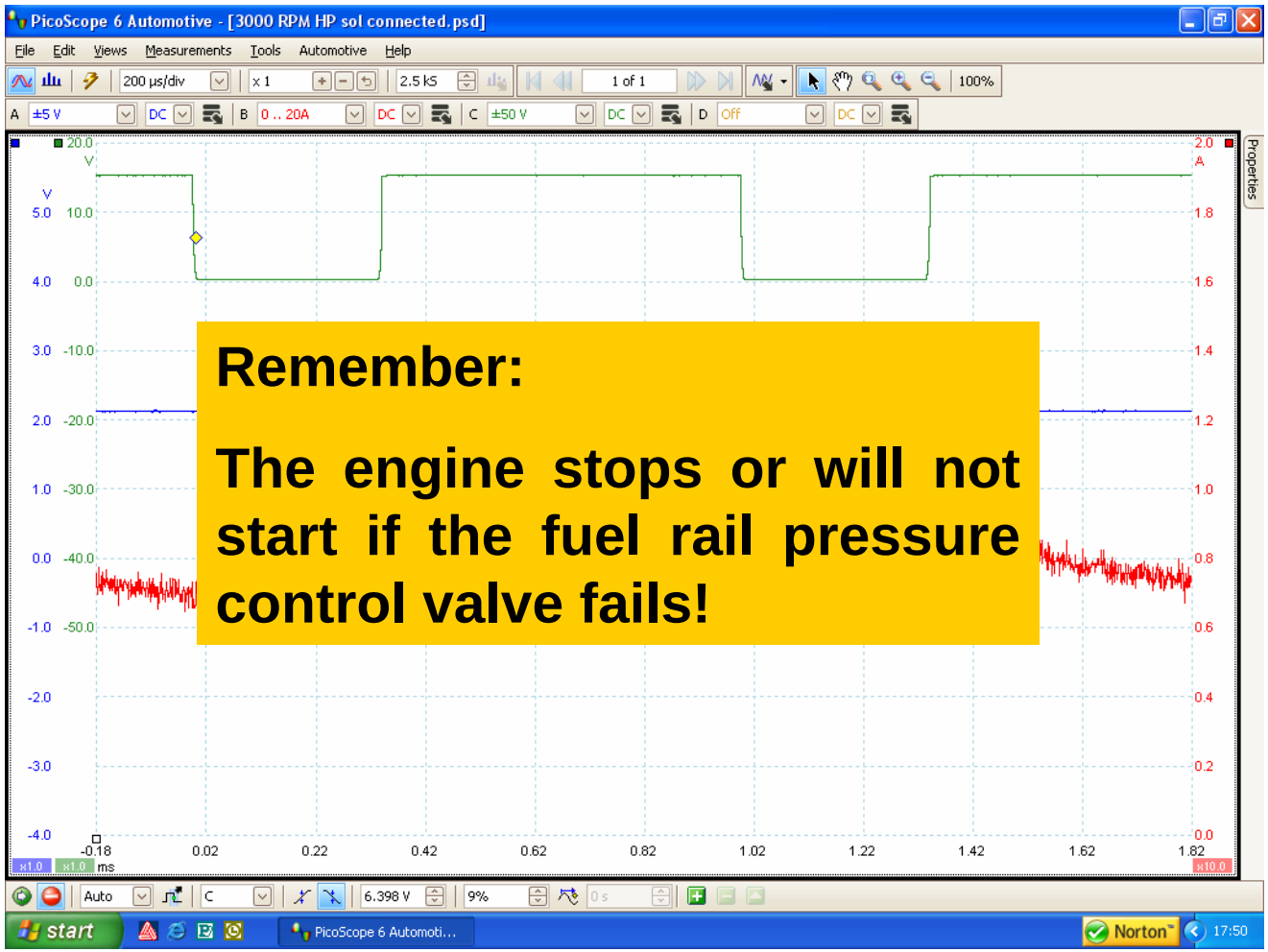

| | 1 | 2 | Δ |
|---|---|---|---|
| □ | -6.0 µs | 340.0 µs | 346.0 µs |
| ■ | 2.13 V | –.– | –.– |
| ■ | 1.062 A | –.– | –.– |

**Green = % duty cycle**
**Blue = rail pressure**
**Red = current draw**

AK TRAINING

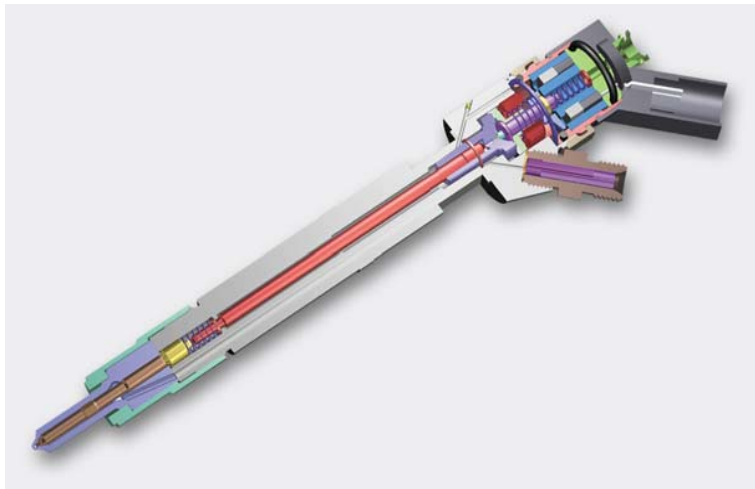
# Common Rail Diesel Fuel Systems

Pressure control valve waveform



# Common Rail Diesel Fuel Systems

## Fuel injectors



The fuel injectors are controlled by either a solenoid or piezo actuator.

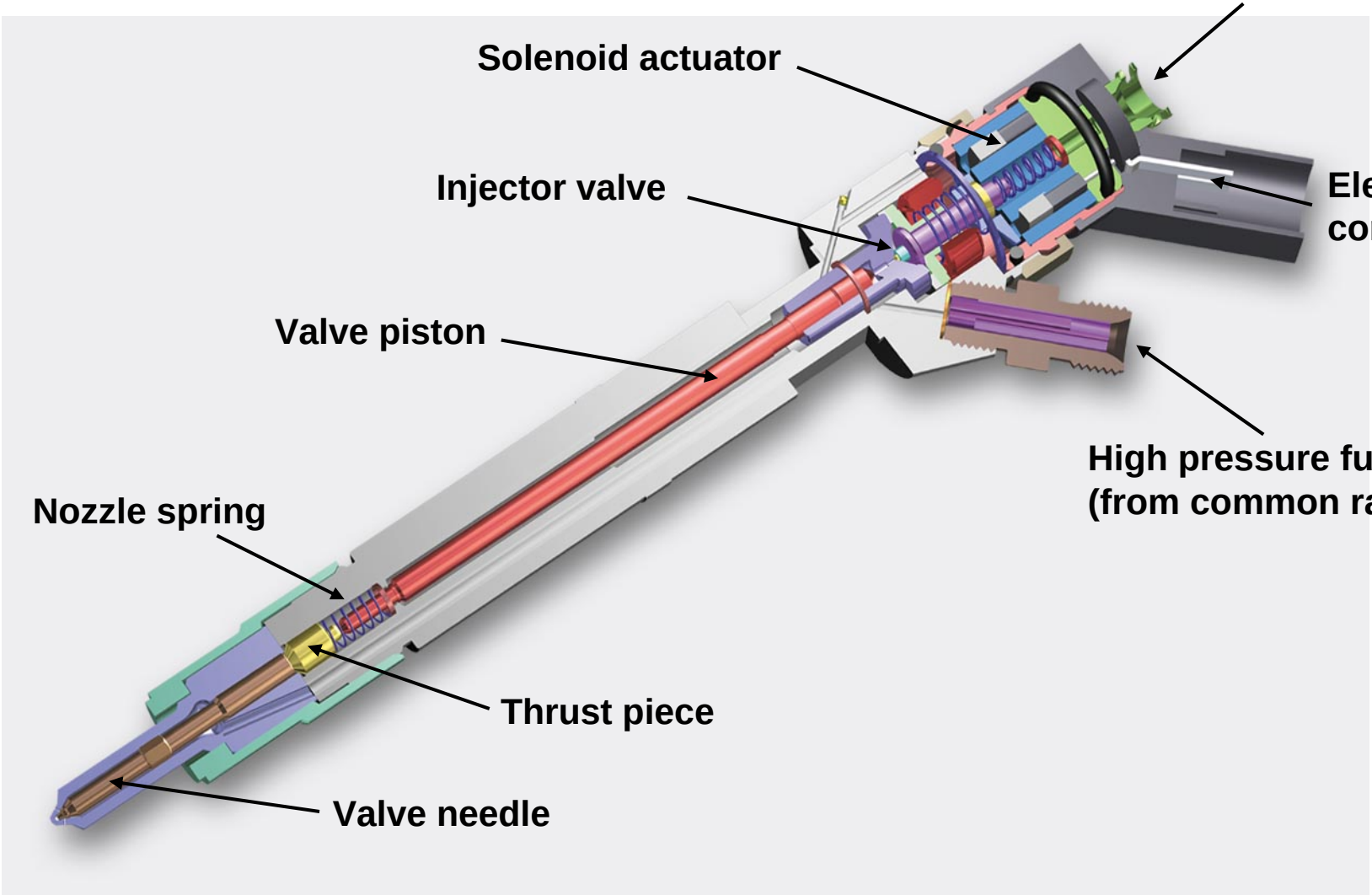
They are energized sequentially by the engine ECM.

The ECM simultaneously switches a live voltage supply and an earth for each injector.

Multiple injection processes per cylinder combustion are possible.

# Common Rail Diesel Fuel Systems

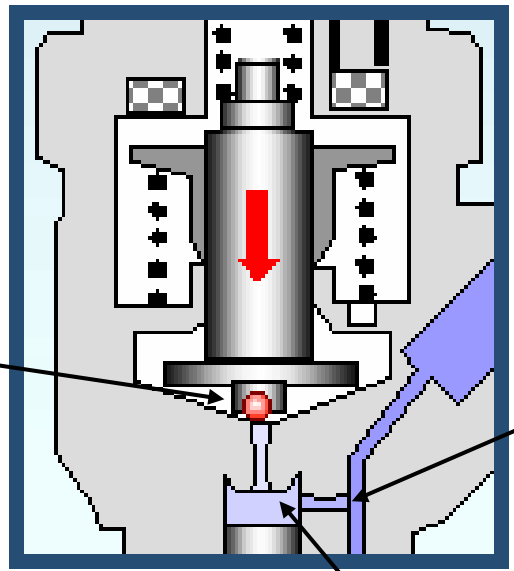
Fuel injectors

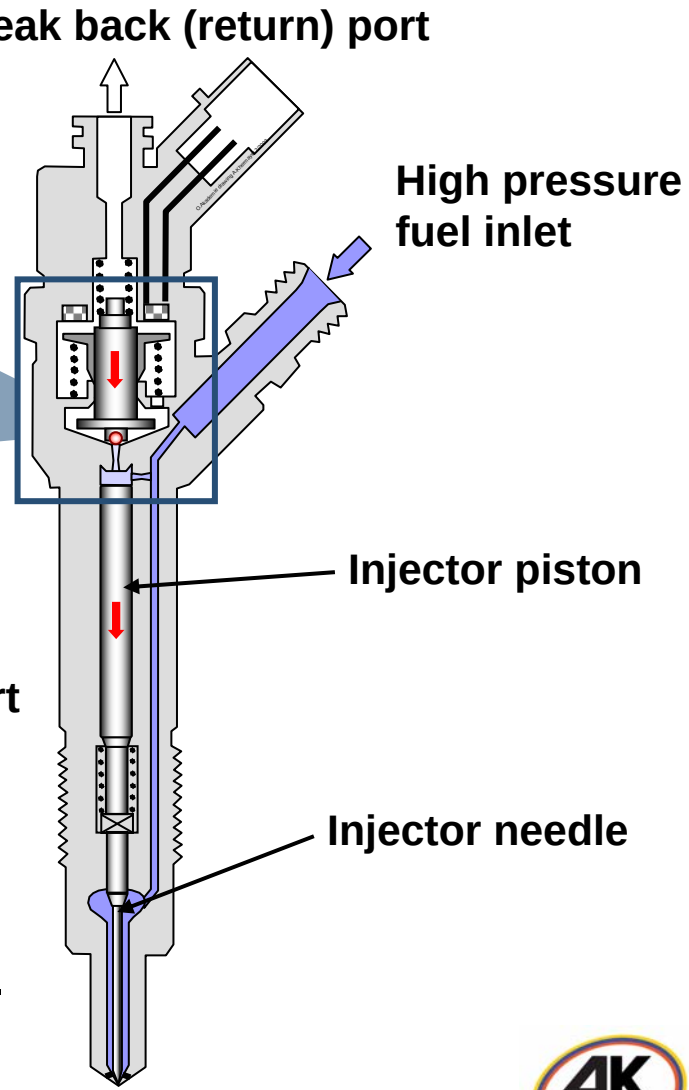


# Common Rail Diesel Fuel Systems

Operation of fuel injectors

Fuel pressure is supplied to the injector needle seat area.....



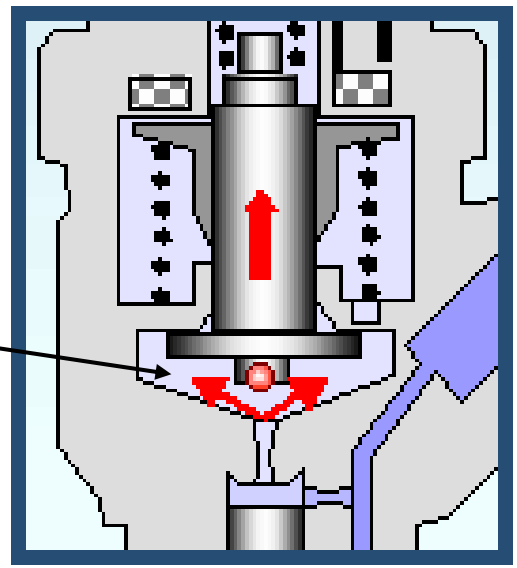




and also to a small chamber above the injector piston via a calibrated inlet port.

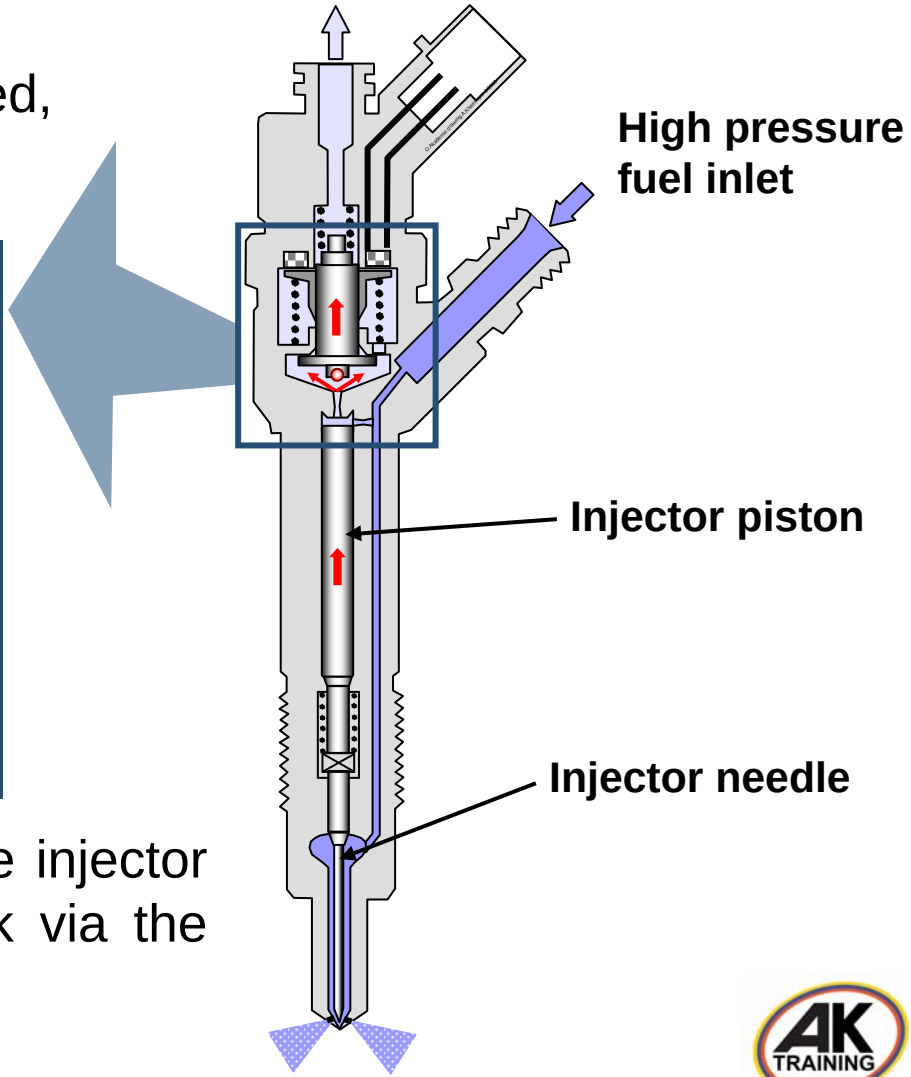
# Common Rail Diesel Fuel Systems

Operation of fuel injectors

When the solenoid is energized, the injector valve opens.



Injector valve opens

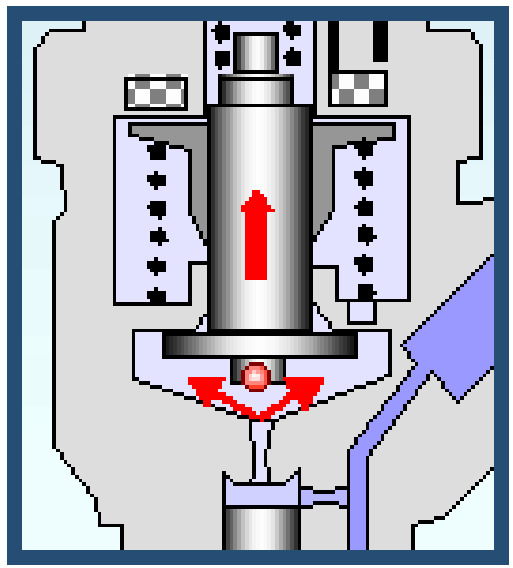


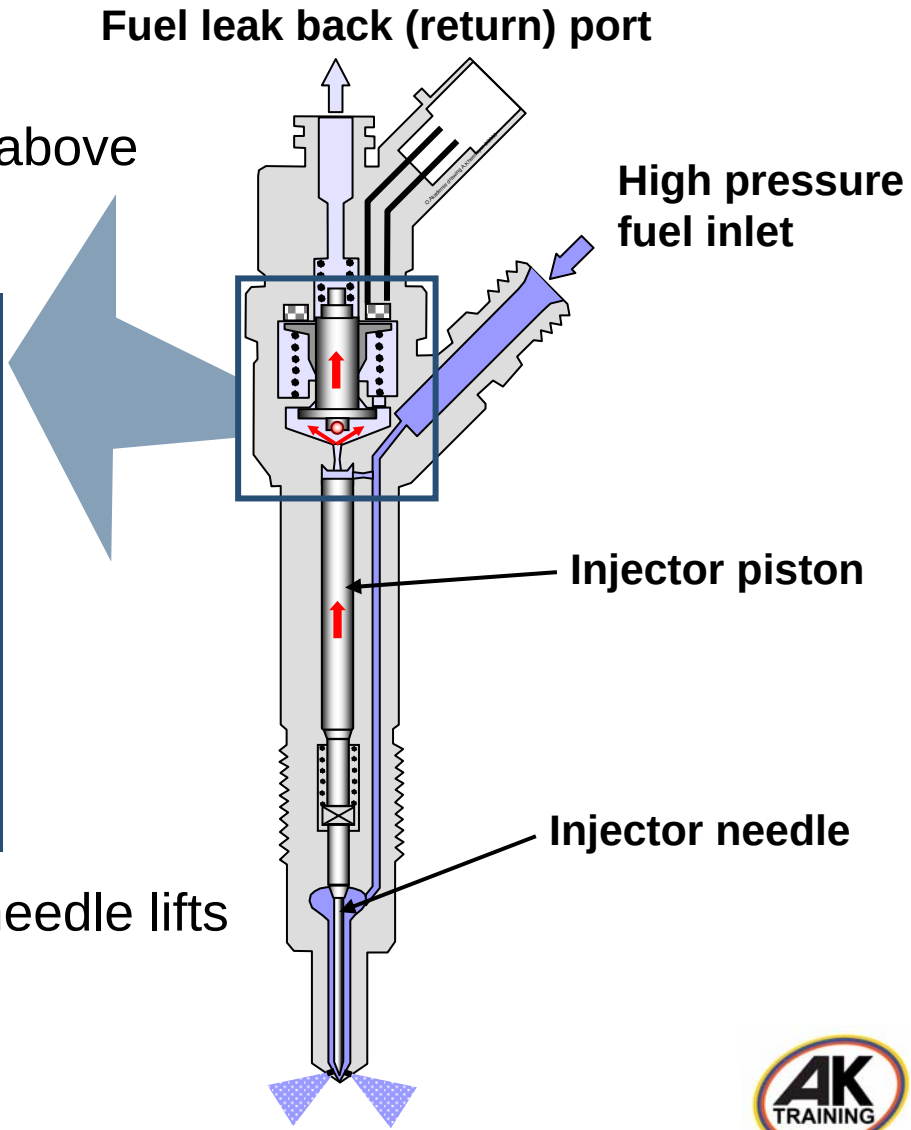

Fuel pressure is relieved above the injector piston and returns to the fuel tank via the injector leak back (return) ports.

# Common Rail Diesel Fuel Systems

Operation of fuel injectors

This creates a pressure difference above and below the injector piston.



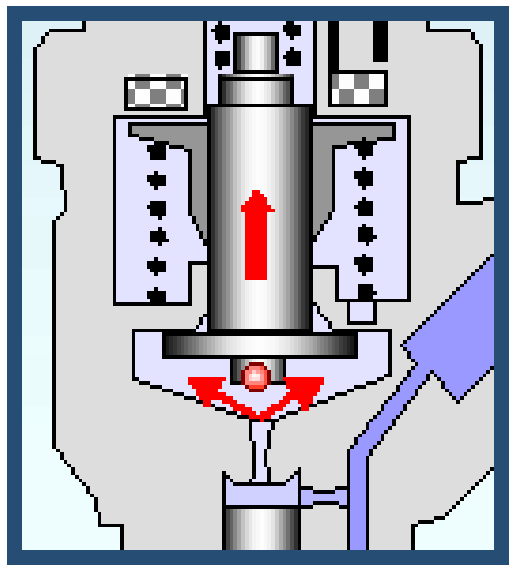


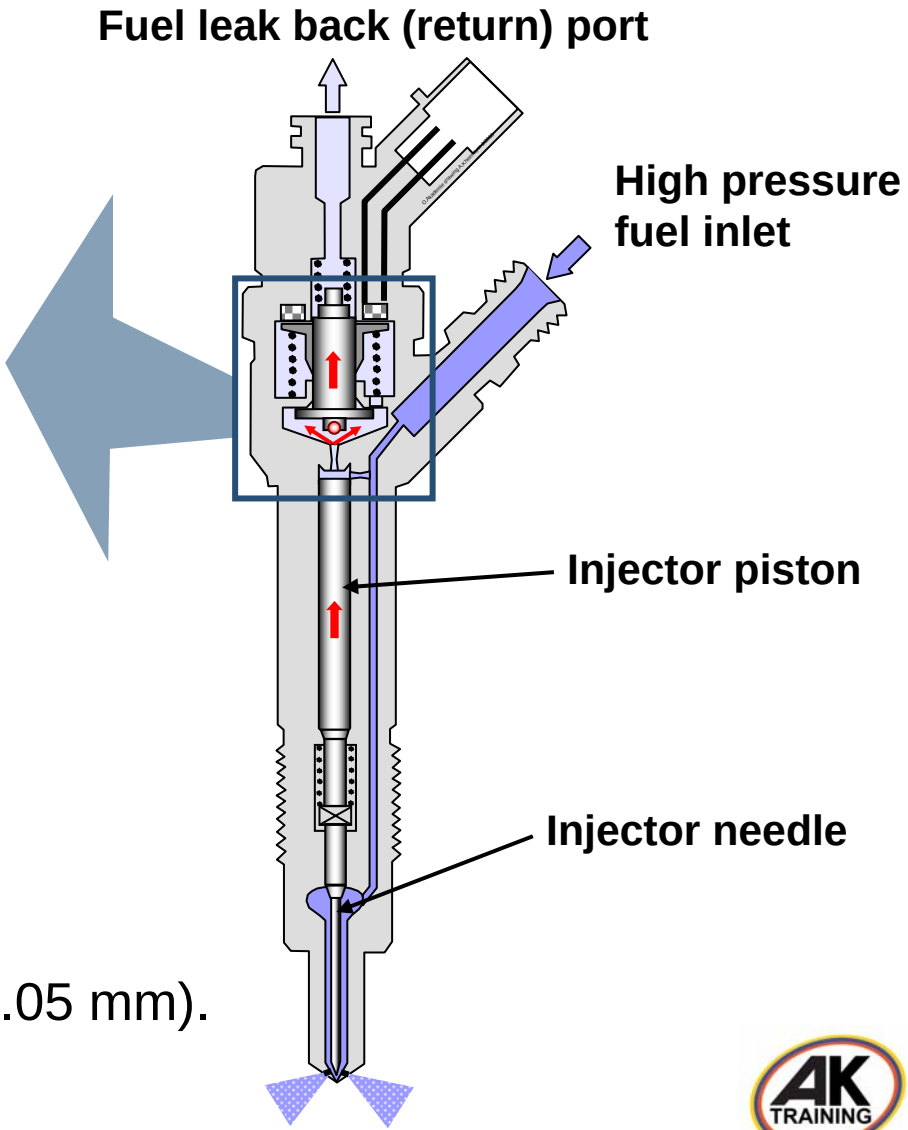

Fuel pressure below the injector needle lifts the needle.

# Common Rail Diesel Fuel Systems

Operation of fuel injectors

Fuel is now injected into the cylinder.



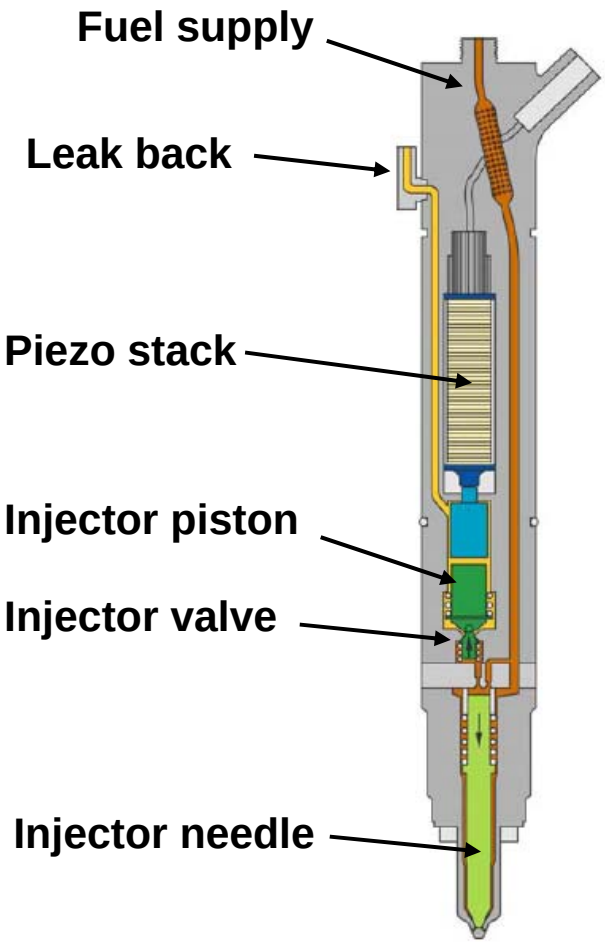



Maximum stroke of solenoid valve:

approximately 50 micrometers (0.05 mm).

# Common Rail Diesel Fuel Systems

## Piezo injector




### Primary advantage:

Quicker response time (up to four times faster than solenoid controlled injector).

### Features

Piezo stack has several hundred wafer thin slices of Piezo crystal material.

When voltage is applied, the piezo stack expands and opens the injector valve.

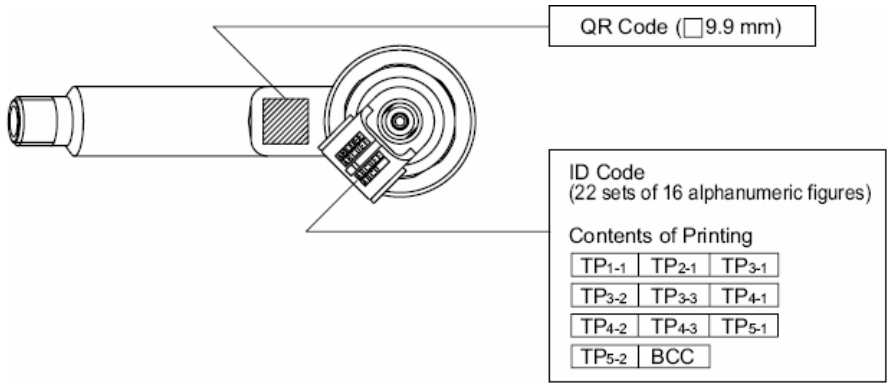
Mechanical principle of operation is similar to the solenoid injector.

# Common Rail Diesel Fuel Systems

## Injector codes

Most injectors have a code that must be programmed into the engine ECM.


**Bosch injector generation 2**
**IMA code for injector flow adjustment**



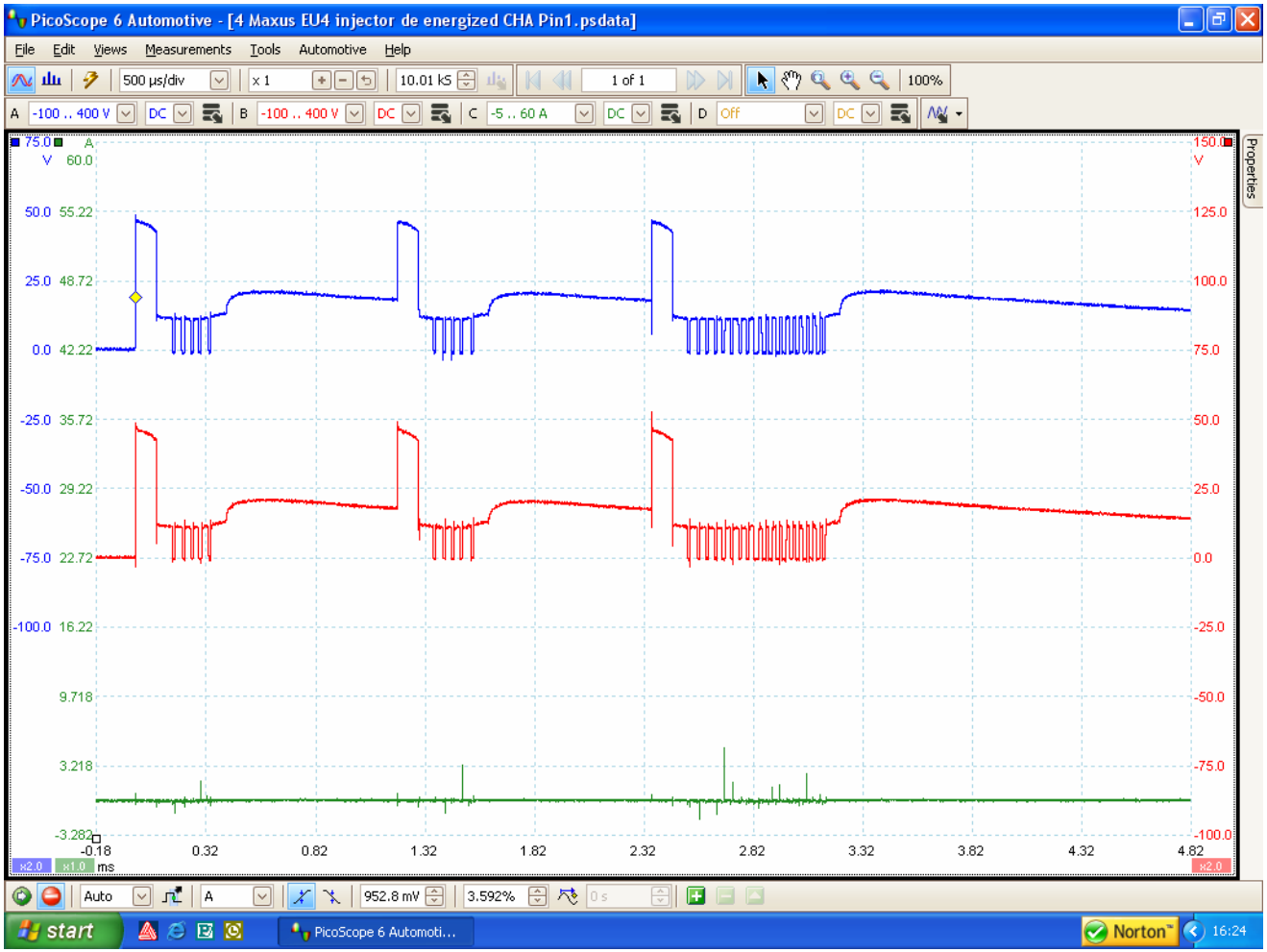

**Denso injector**
**QR (Quick Response) code**

The code relates to the calibrated flow rate of the injector.

It enables the ECM to correct the injection quantity to compensate for manufacturing tolerances.

# Common Rail Diesel Fuel Systems

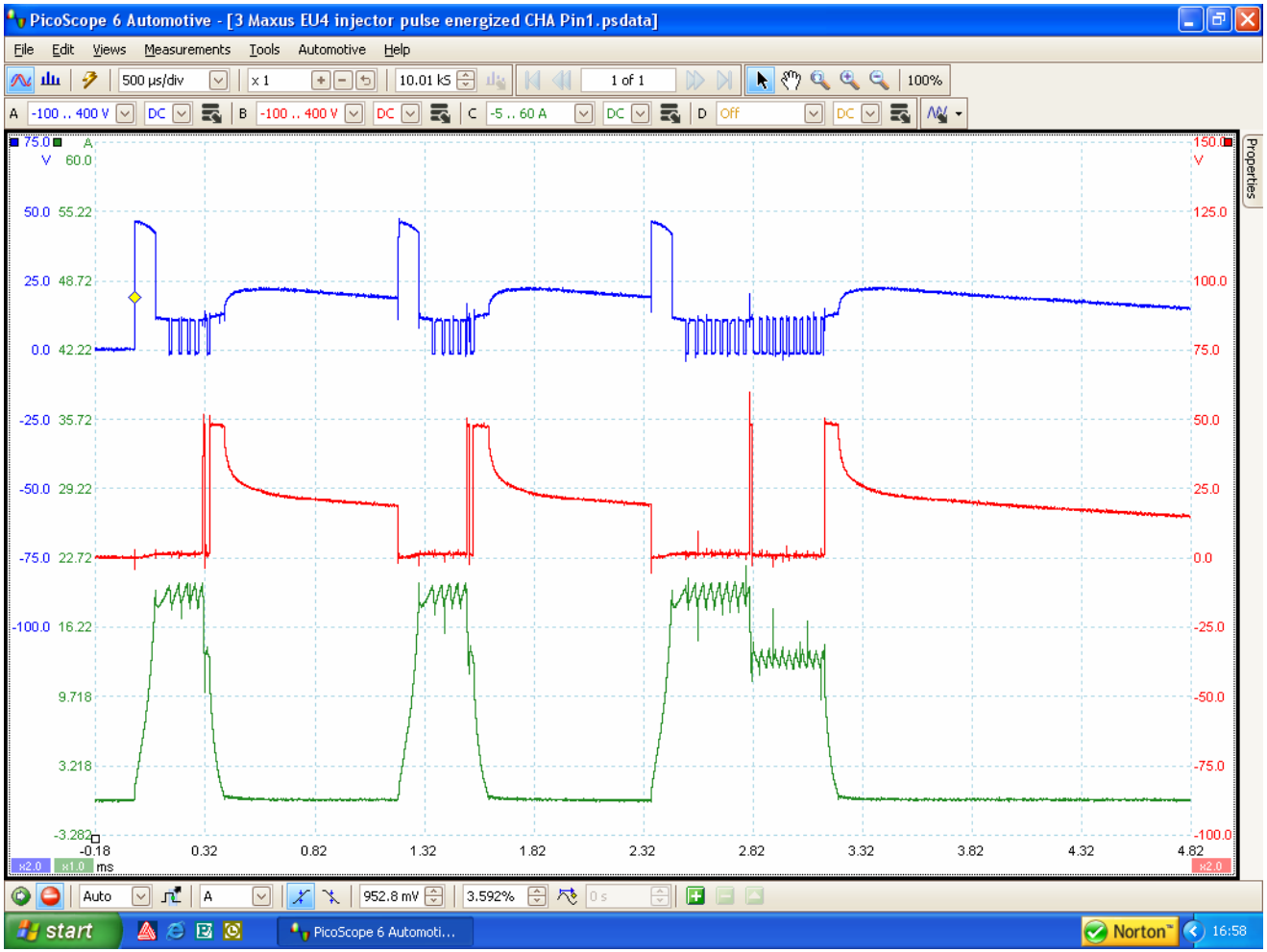
## Oscilloscope waveform: Solenoid injector de energized




**Blue** = switched +
**Red** = switched -
**Green** = current draw

# Common Rail Diesel Fuel Systems

## Oscilloscope waveform: Solenoid injector energized

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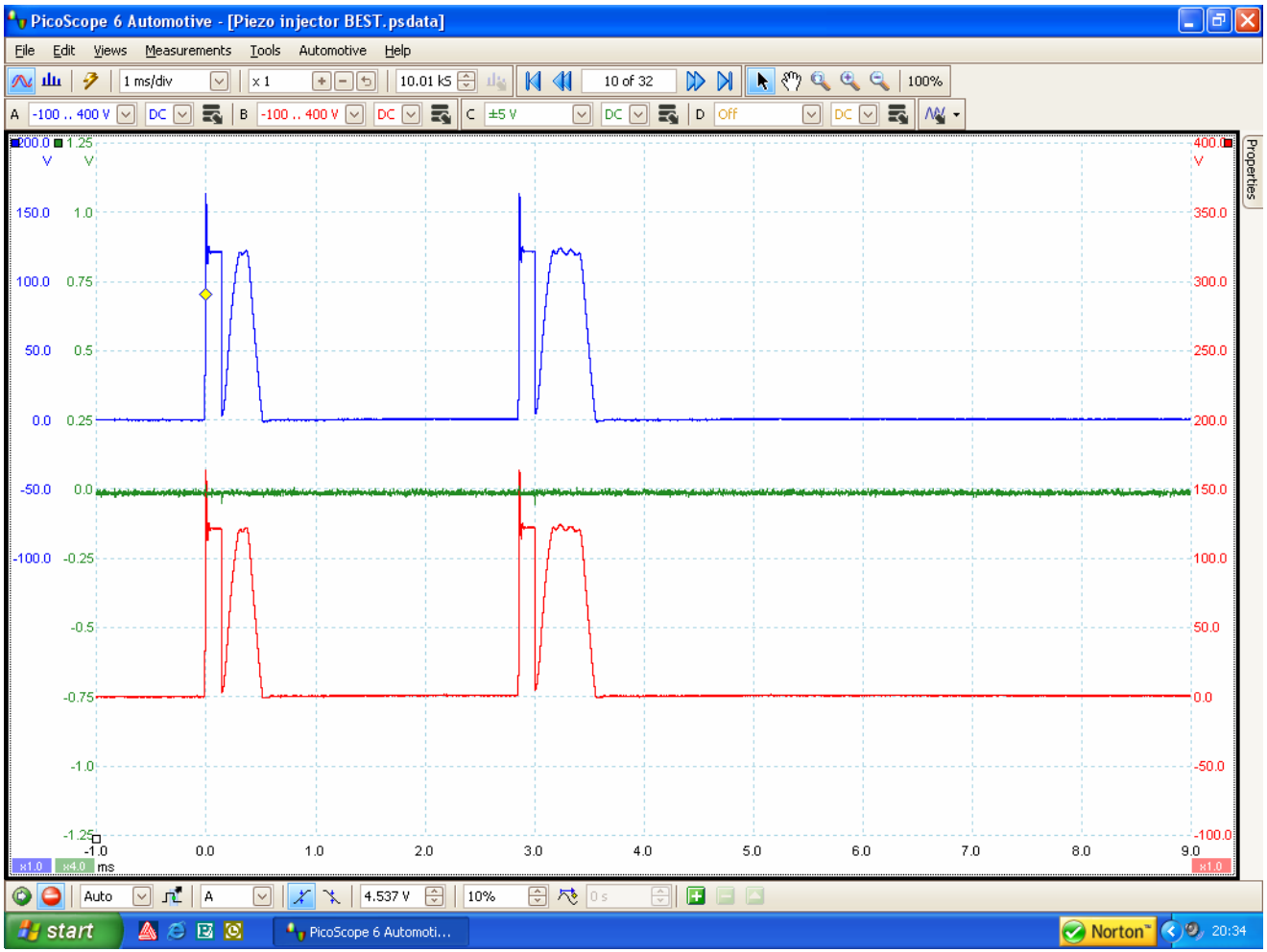
# Common Rail Diesel Fuel Systems

## Oscilloscope waveform: Piezo injector de energized




**Blue = switched +**
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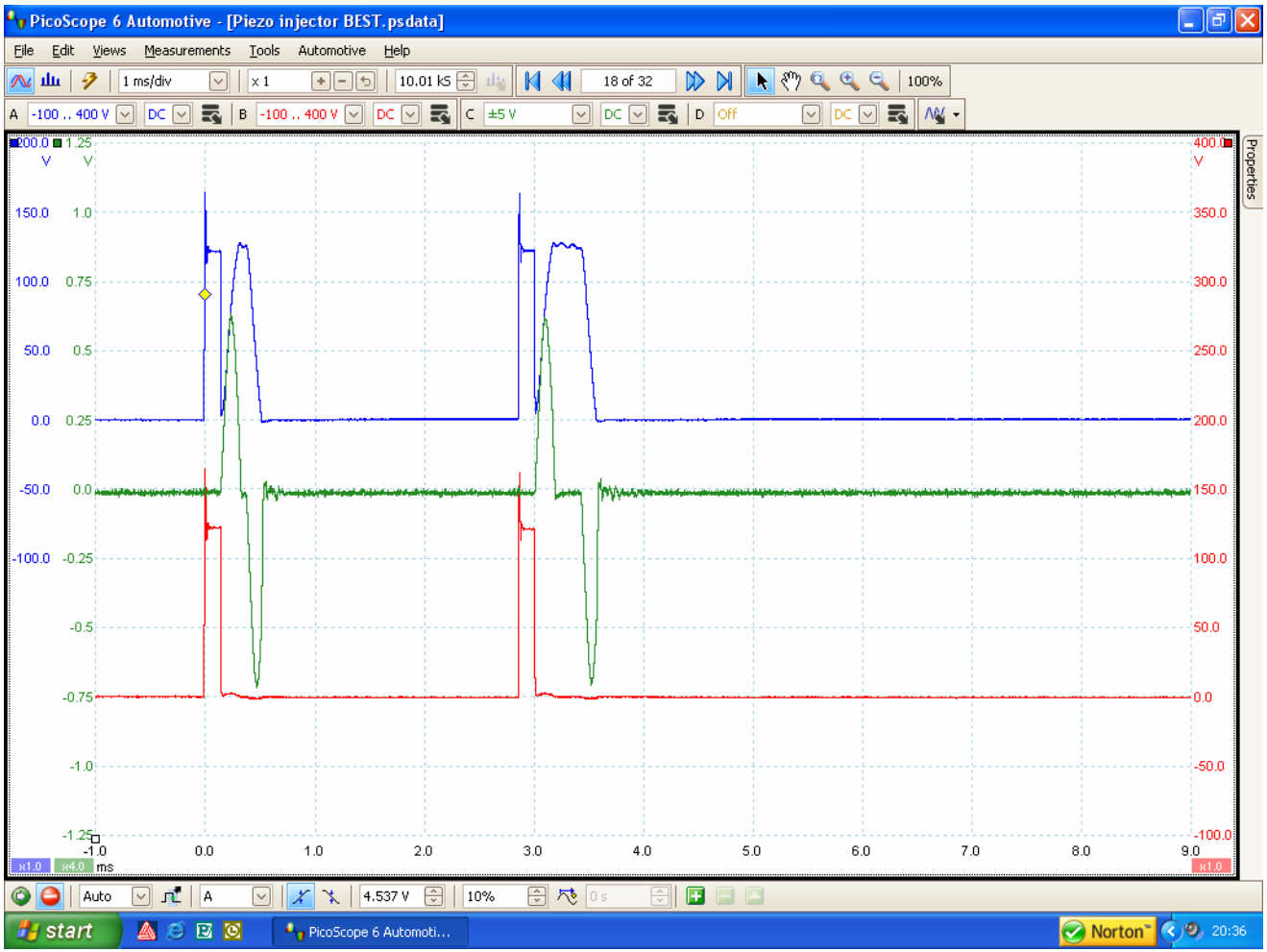
# Common Rail Diesel Fuel Systems

## Oscilloscope waveform: Piezo injector energized




**Blue = switched +**
**Red = switched -**
**Green = current draw**

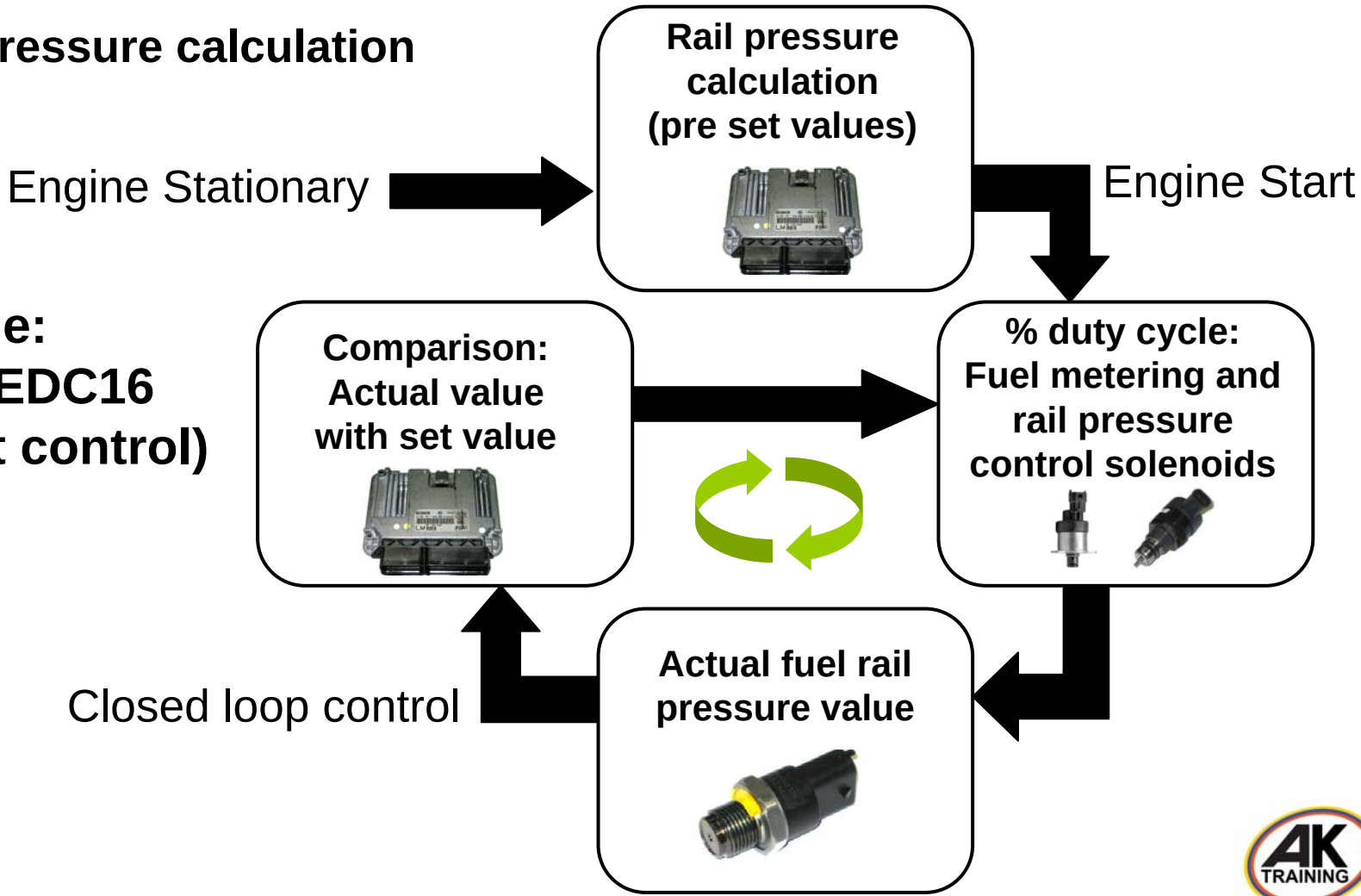
AK TRAINING

# Common Rail Diesel Fuel Systems

Engine management closed loop control functions:

**Rail pressure calculation**

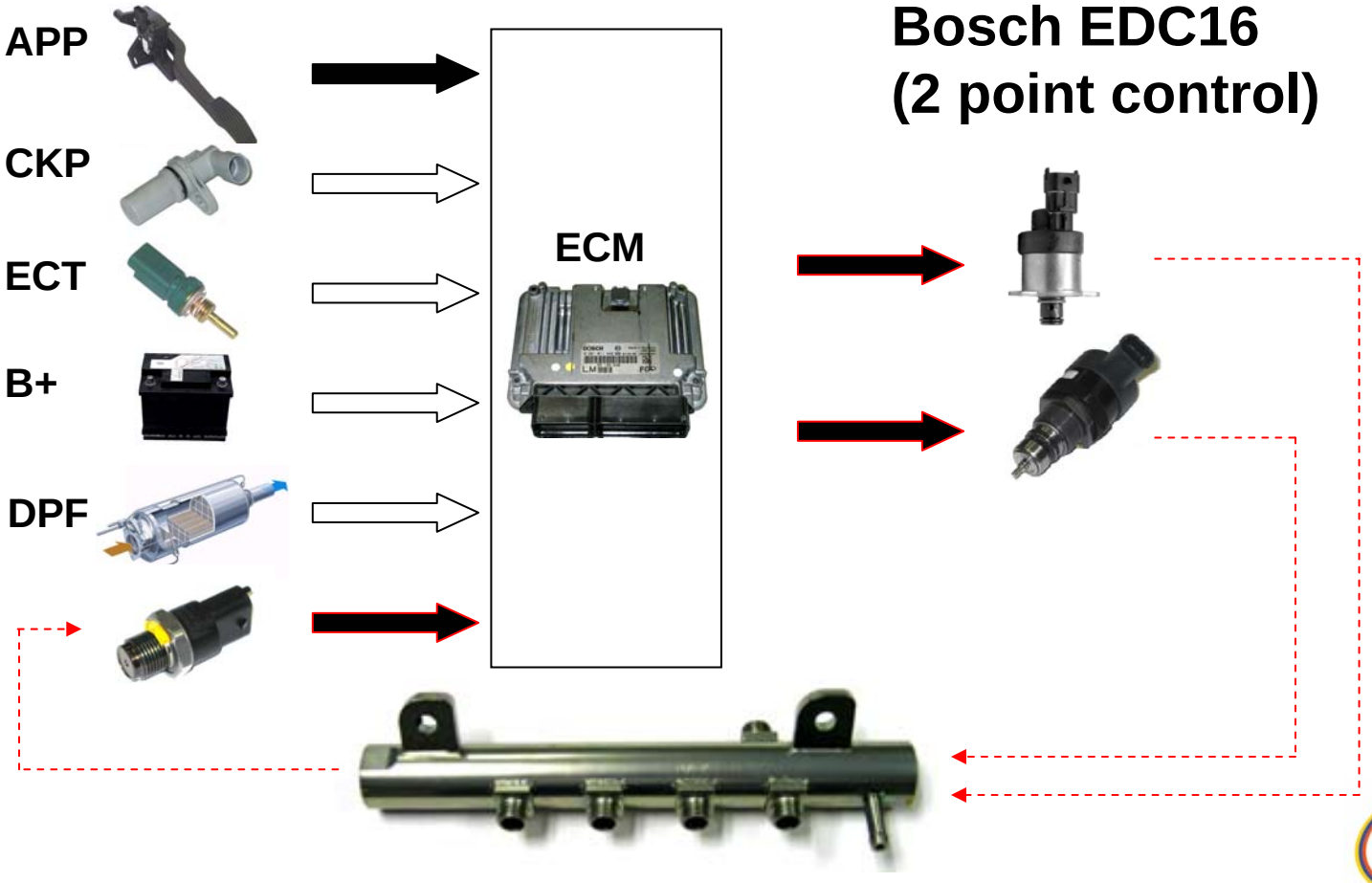
**Example:**
**Bosch EDC16**
**(2 point control)**



# Common Rail Diesel Fuel Systems

Engine management closed loop control functions:

**Rail pressure calculation**




**Example:**
**Bosch EDC16**
**(2 point control)**

# Common Rail Diesel Fuel Systems

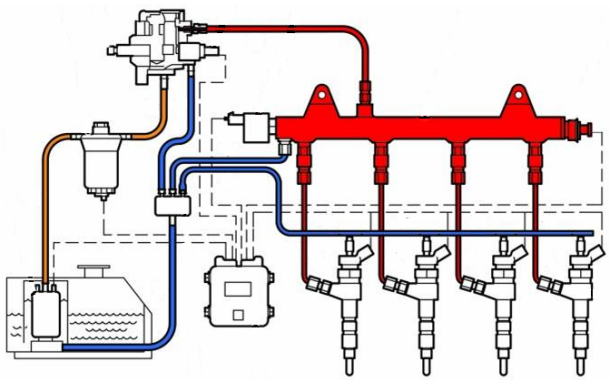
## Fuel system diagnosis

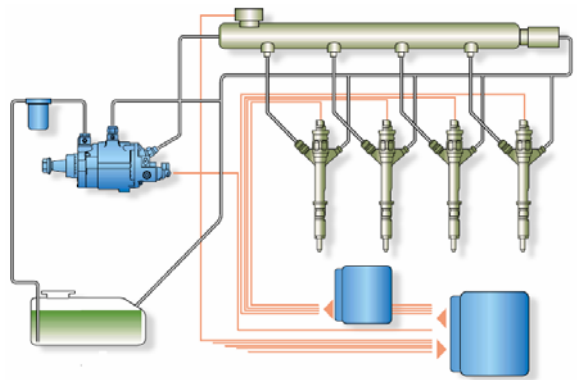
Common rail diesel fuel systems operate on a closed loop basis.

The system carries out a great many complex calculations to precisely control fuel quantity and injection timing.

A range of tools and test equipment is commercially available to assist with diagnosis of the system.

The following is a brief overview to highlight some of the basic tests that can be carried out to diagnose faults with the system.

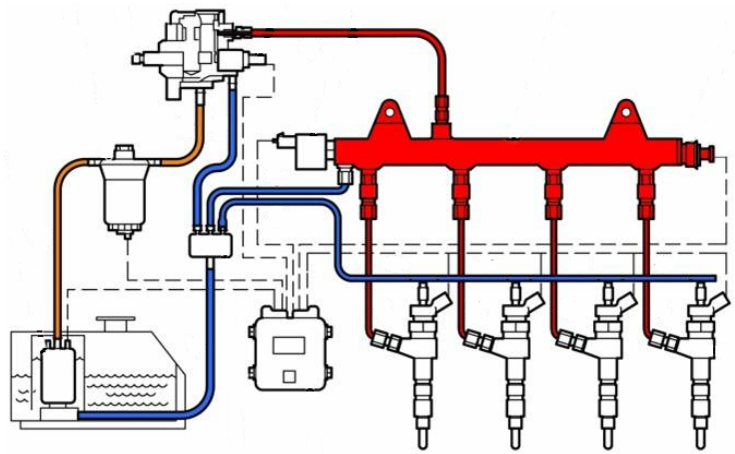




# Common Rail Diesel Fuel Systems

Fuel system diagnosis

**Basics first!**

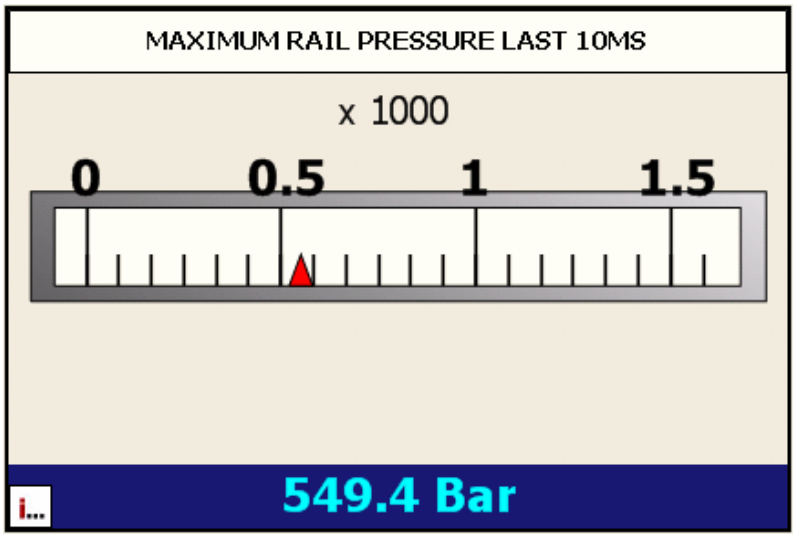


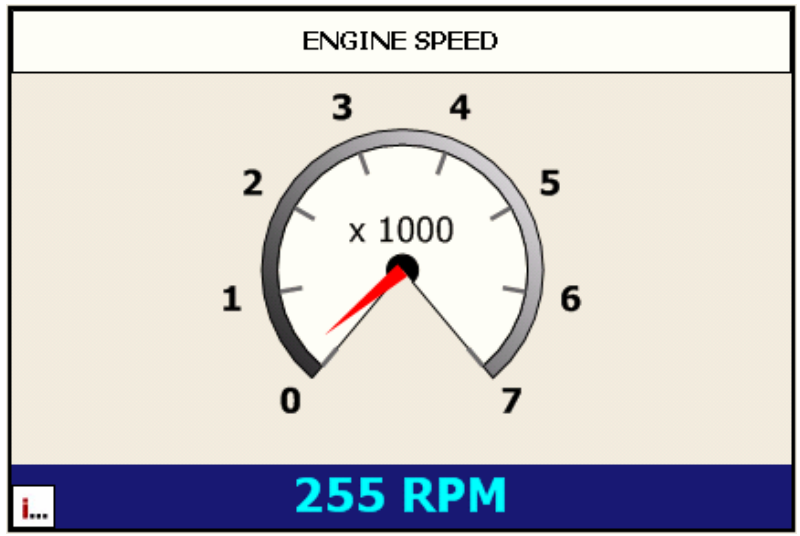
- Sufficient diesel in the fuel tank?
- Fuel contamination (eg from petrol).
- Fuel leaks and damage to components.
- Battery state of charge?
- Adequate low pressure fuel supply from fuel tank?
- Does engine start or crank and try to start?
- Is white smoke emitted from exhaust during engine cranking? (not always easy to see but indicates some fuel is entering cylinders).
- Are any DTC's stored in fault memory of engine ECM?

# Common Rail Diesel Fuel Systems

## Fuel system diagnosis

Is the system capable of generating sufficient fuel pressure?




Typical minimum '**manufacturer specified**' value during engine cranking:

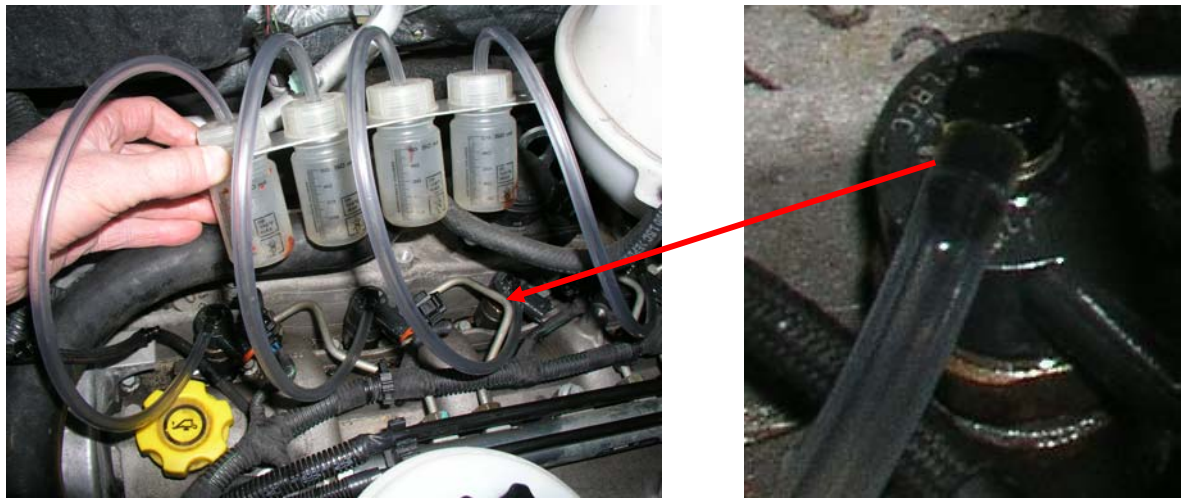
approximately between 200 – 300 Bar

In practice, the figure is usually higher for a good system. Above example shows fuel pressure during engine cranking.

# Common Rail Diesel Fuel Systems

Fuel system diagnosis

Injector leak back test



There should **not** normally be any fuel collected in receptacles during engine cranking.

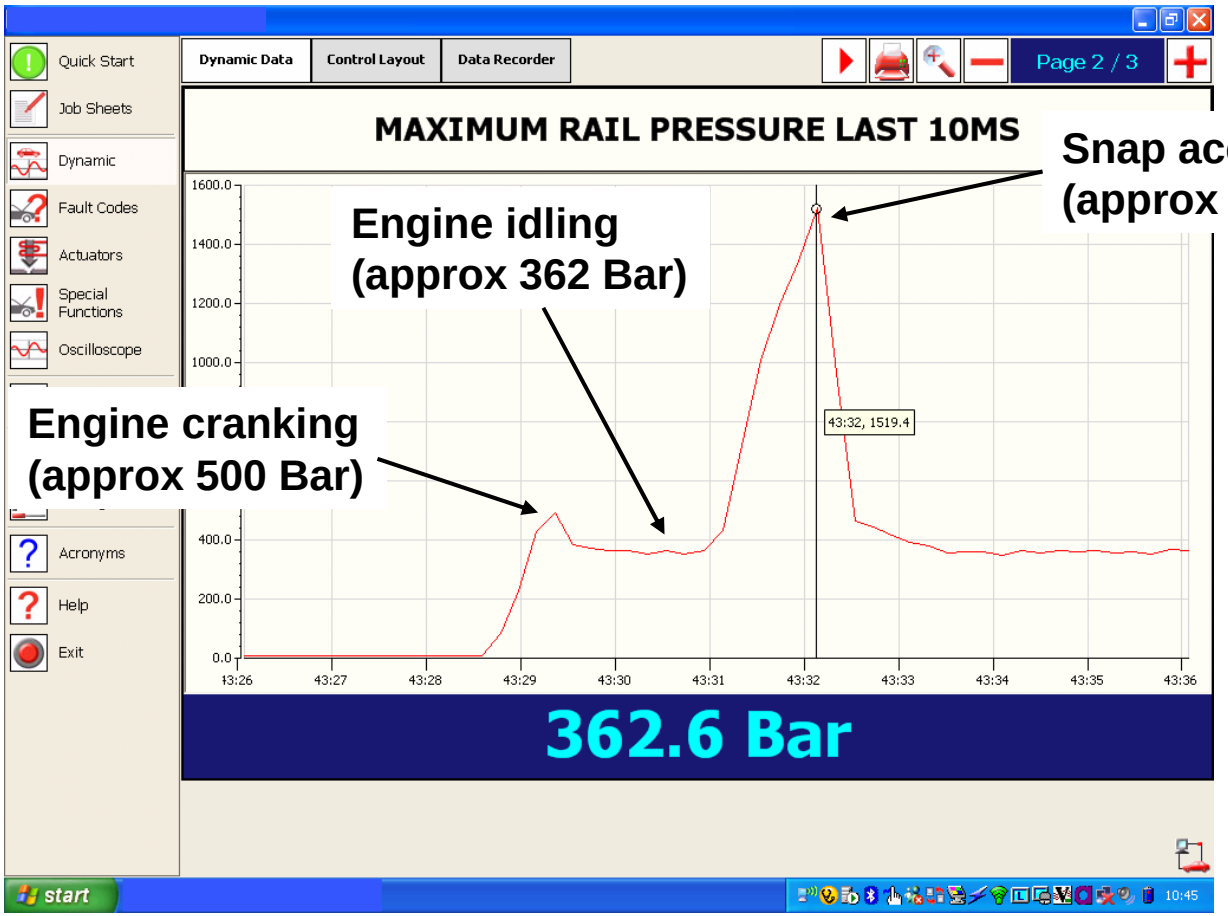
Example of acceptable leak back value with engine idling:

approximately 20ml per injector over a 2 minute period.
**(Always refer to manufacturer data for exact specifications)**

# Common Rail Diesel Fuel Systems

Fuel system diagnosis

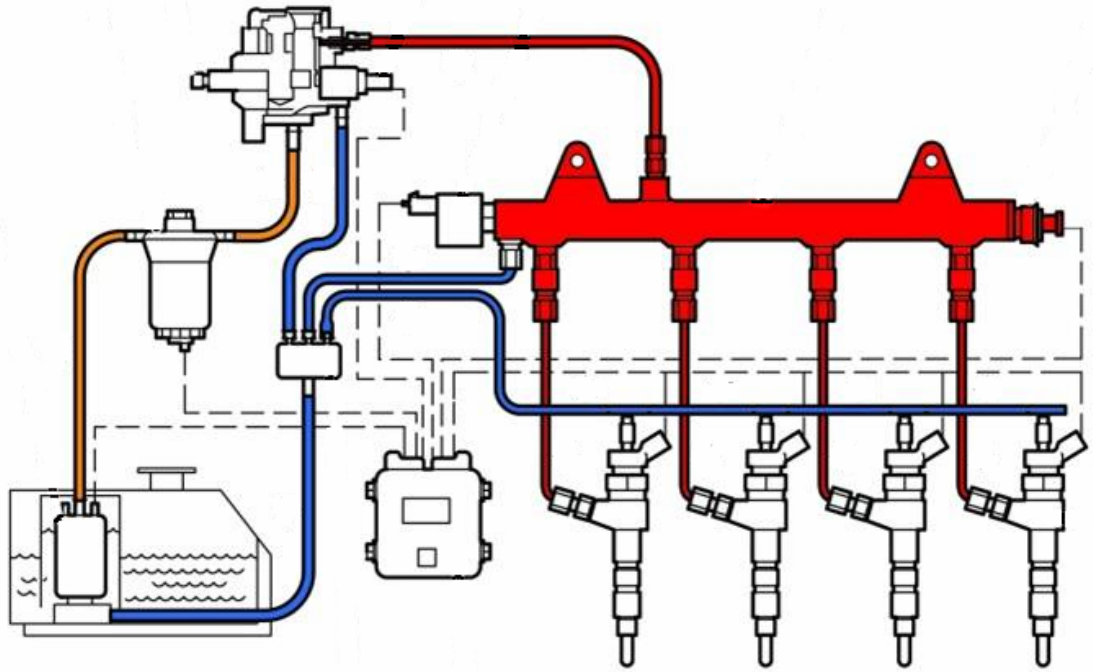
Maximum fuel pressure



# Thank you

## for attending a technical overview of

# Common Rail Diesel Fuel Systems



presented by

**Tony Kitchen**
**(AK Training)**