Fuel Injection Fundamentals

Presented by Bill Burris
PCA Technical Committee

Let's put the Fun back in Fundamentals!

Agenda – What you can expect

- **Welcome & personal introduction**
- **Start with the basics: Not the *why* nor necessarily the *how*, primarily the *what***
- **Fuel Injection Theory**
- **Brief Overview of Porsche Fuel Injection systems**
- **Along the way, we'll look into the functions of the parts themselves**
  - **Injectors**
  - **Fuel pump**
  - **Pressure regulators/dampers**
  - **Oxygen sensor**
  - **Other fuel-related systems like evaporative emission controls and catalytic converters**
- **Model-specific questions & answers!**

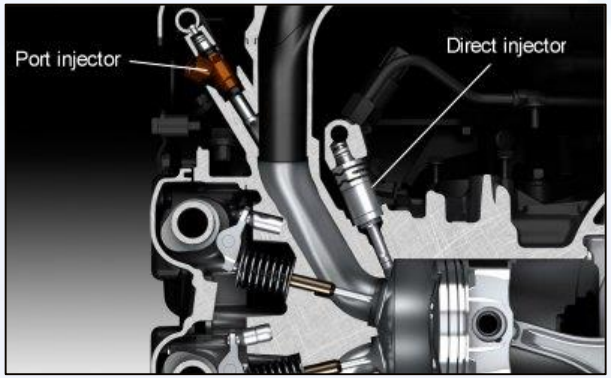
Fuel Fundamentals

$$C_8H_{18} + 12.5\,(O_2 + 3.776N_2) = 8CO_2 + 9H_2O + 47.2N_2$$

Gasoline | Air | Carbon Dioxide | Water | Nitrogen

We're NOT going to get into the chemistry or the thermodynamics, we'll stick mainly to car parts and what they do.

But first …



Fuel Fundamentals

Let's start by looking at how SIMPLE fuel injection is

$$V = P \times T \times A$$

V = Volume of fuel through the injector

P = Fuel pressure behind the injector

T = Time the injector is open

A = Area of the injector orifice

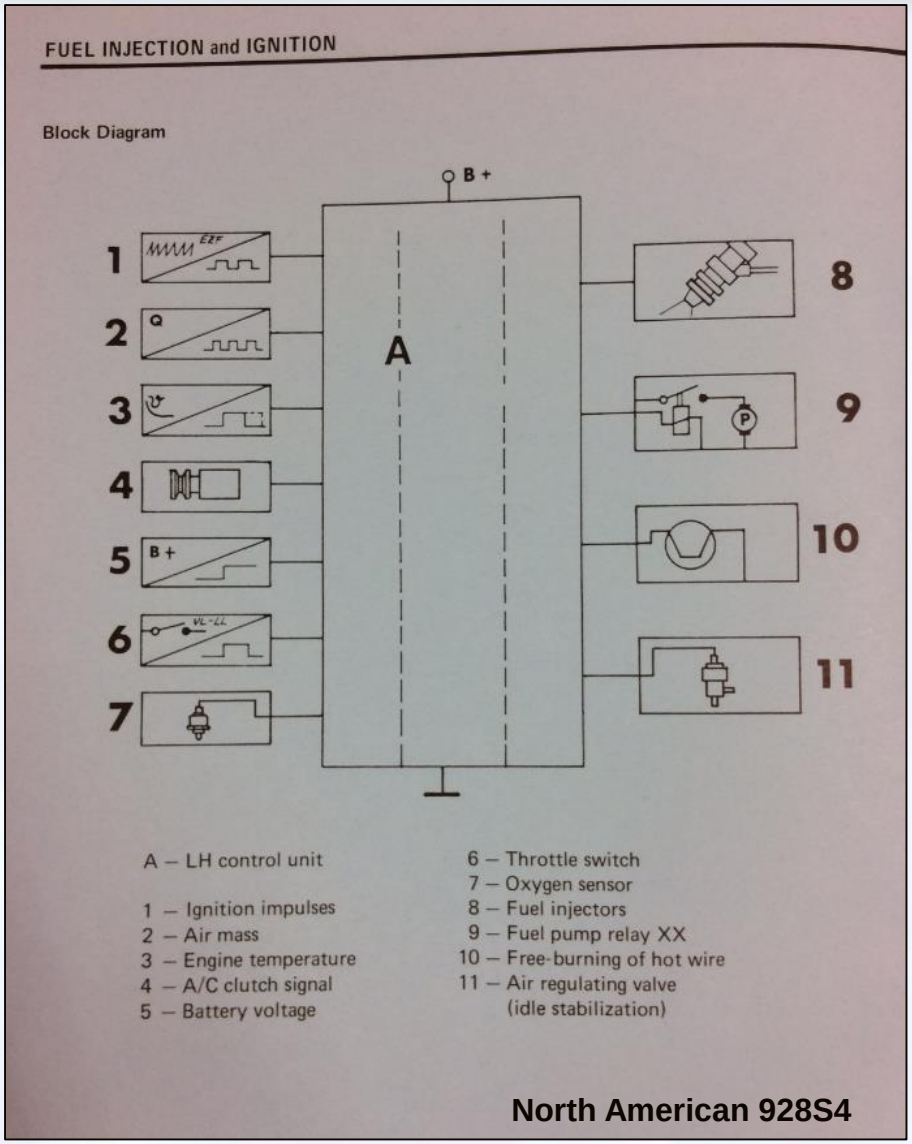
CIS (K-Jetronic)
MPI (D-Jetronic)
AFC (L-Jetronic)
DME (Motronic)

Fuel Fundamentals

Which inputs are most important?		What are the outputs?
Engine speed & throttle position	Mechanical Fuel Injection MFI Bosch Mechanical	Metered fuel through a mechanical injector, pulsed flow
Engine speed & throttle position	Continuous Injection System CIS Bosch K-Jetronic	Metered fuel through a mechanical injector, continuous flow
Engine speed & throttle position	Manifold Pressure Injection MPI Bosch D-Jetronic	Ground pulse to an electric injector
Engine speed & throttle position	Air Flow Control AFC Bosch L-Jetronic	Ground pulse to an electric injector
Engine speed, TDC & throttle position	Digital Motor Electronic DME Bosch Motronic	Ground pulse to an electric injector
Engine speed, TDC & throttle position	Hot Wire Bosch LH-Jetronic	Ground pulse to an electric injector
Engine speed, TDC & throttle position	Gasoline Direct Injection GDI Bosch Motronic	Ground pulse to a high pressure electric injector

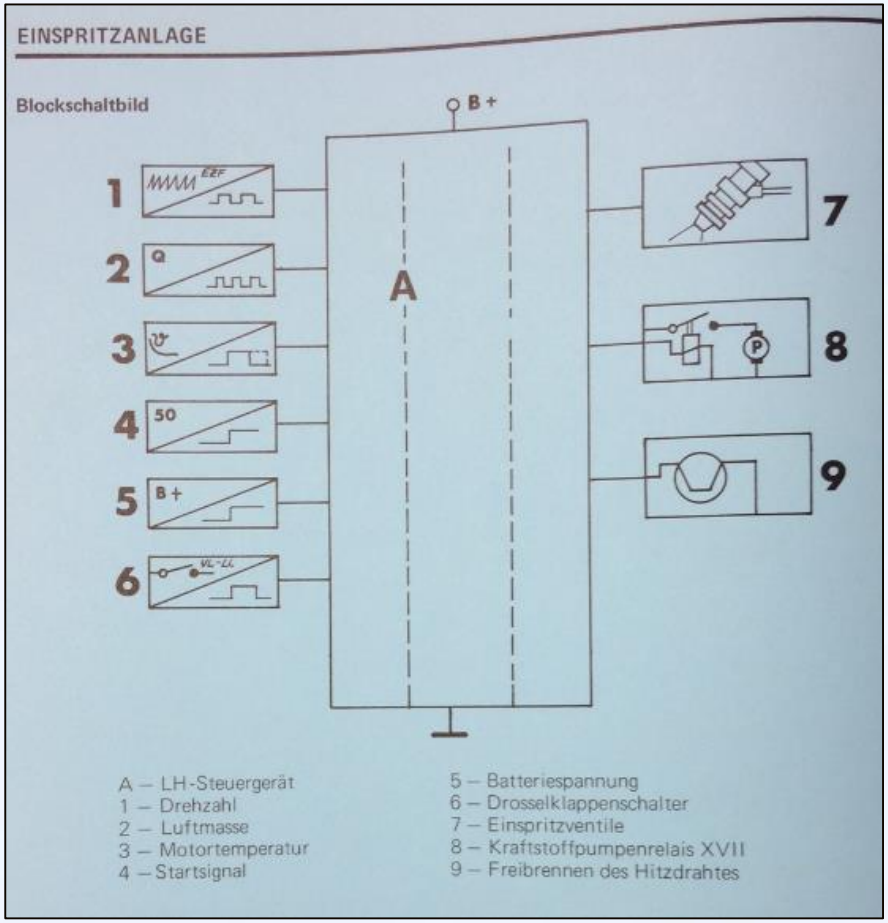
Note: All systems use an electric fuel pump!

Fuel Controller Inputs / Outputs



North American 928S4

Here's an example from the 928S4

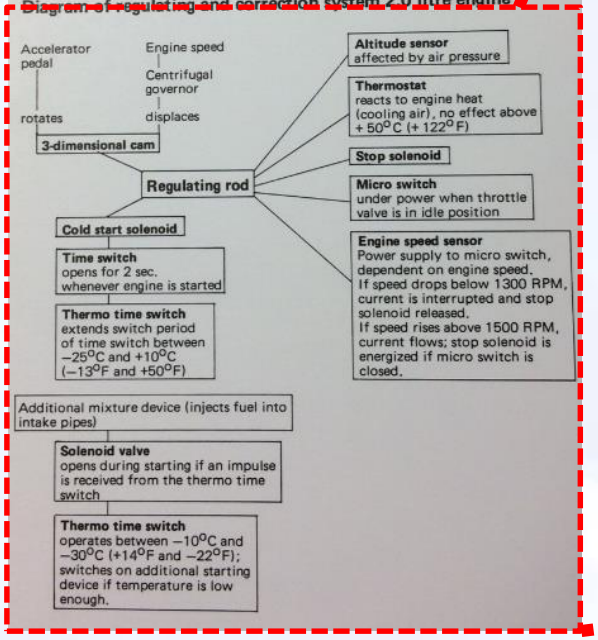


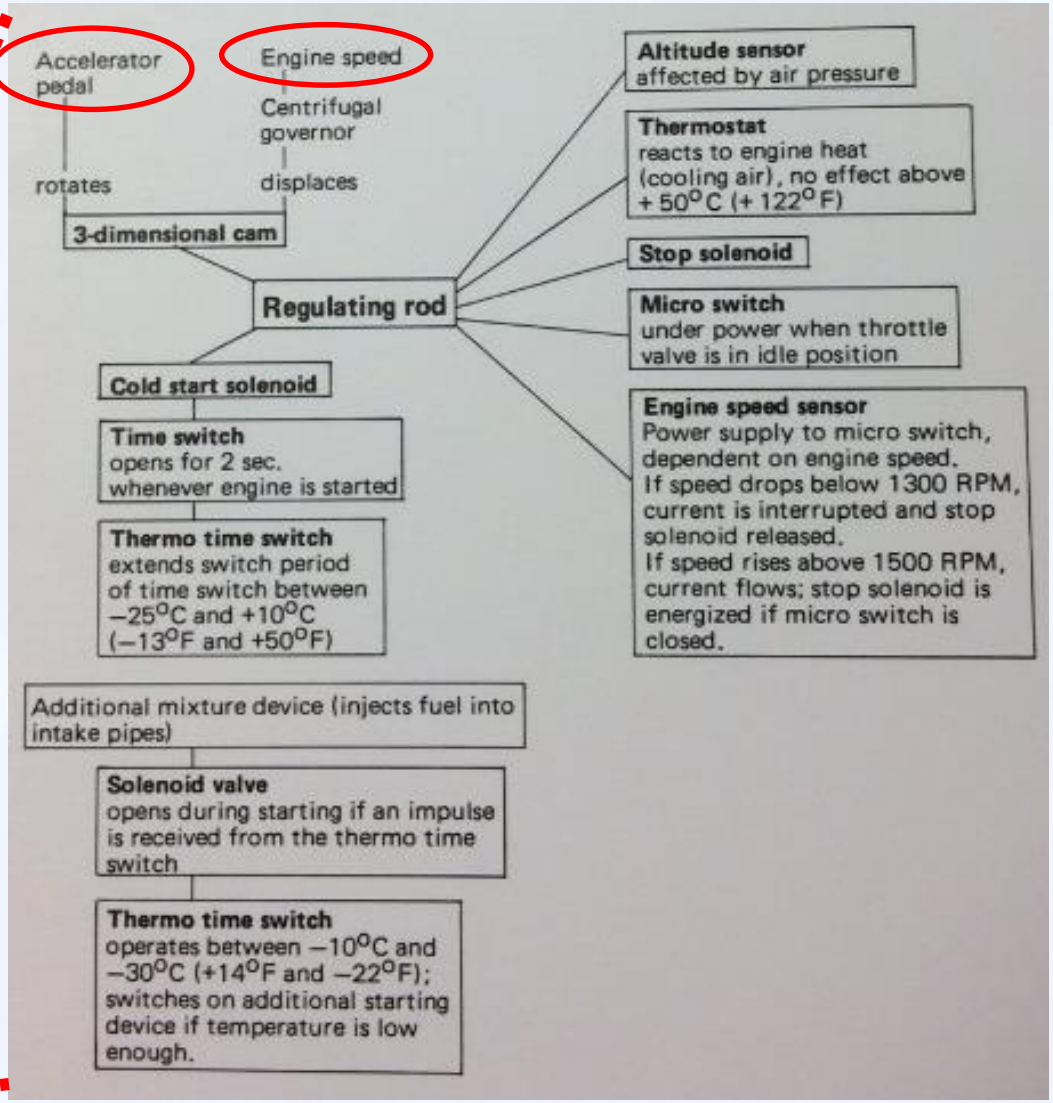
European 928S4

Fuel Controller Inputs / Outputs

Now here's a blast from the past but the same basic idea, this time they're focusing on the inputs to a mechanical rod

Diagram of regulating and correction system 2.0 litre engine





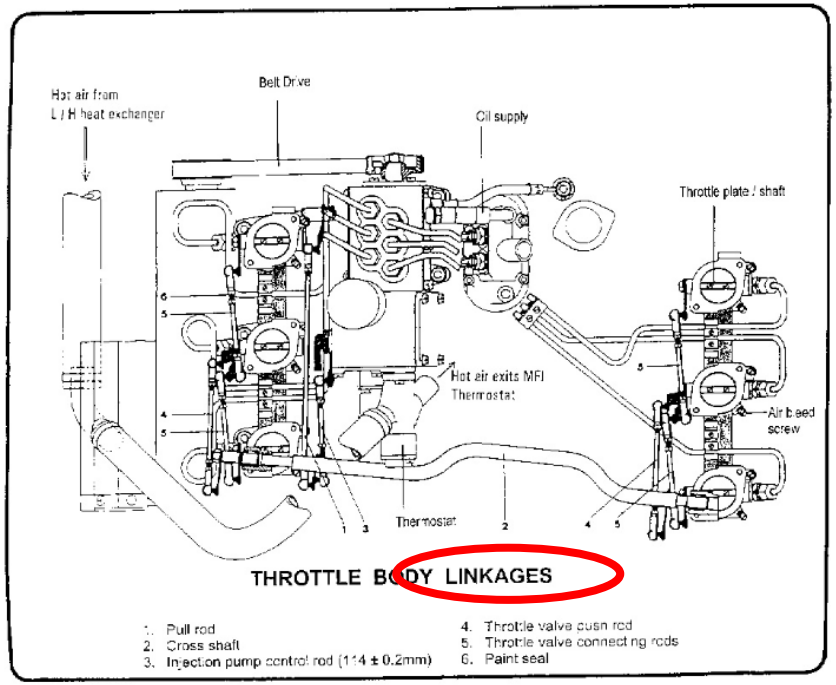
Think About It

Q: If the fundamentals are covered by engine speed and throttle position, why is Bosch adding other controls?
A: Because the engine doesn't perfom they way they want it to under certain conditions.

Mechanical Fuel Injection MFI

Bosch Mechanical

Bosch Mechanical Fuel Injection



Bosch Mechanical Fuel Injection

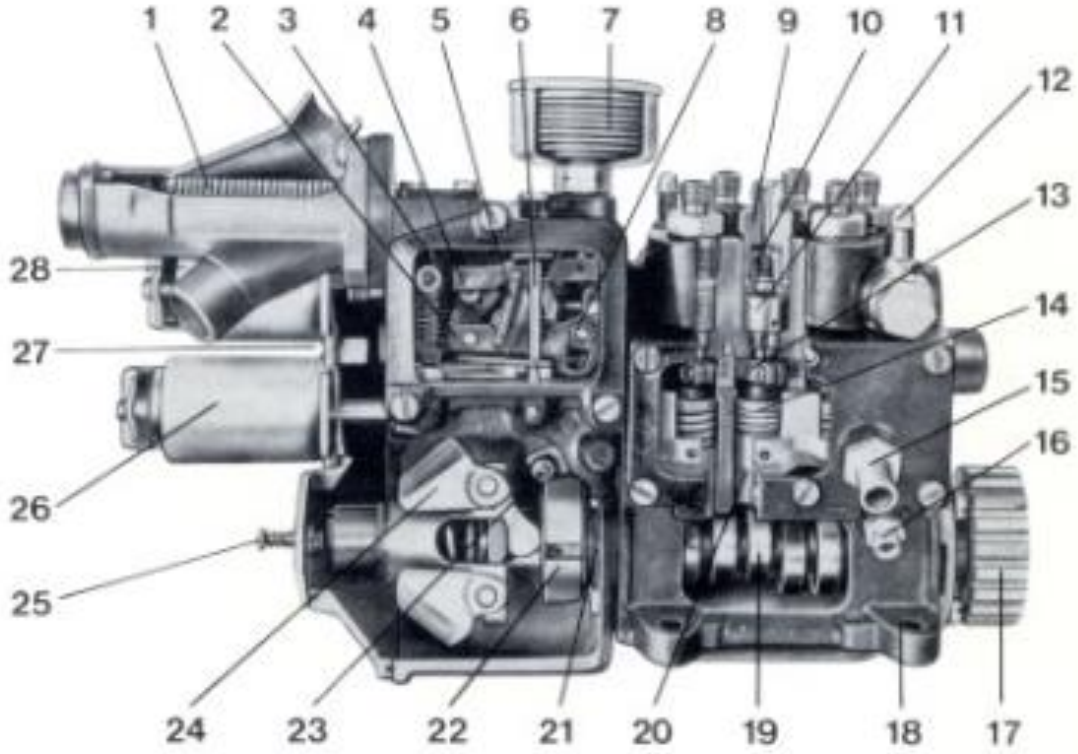
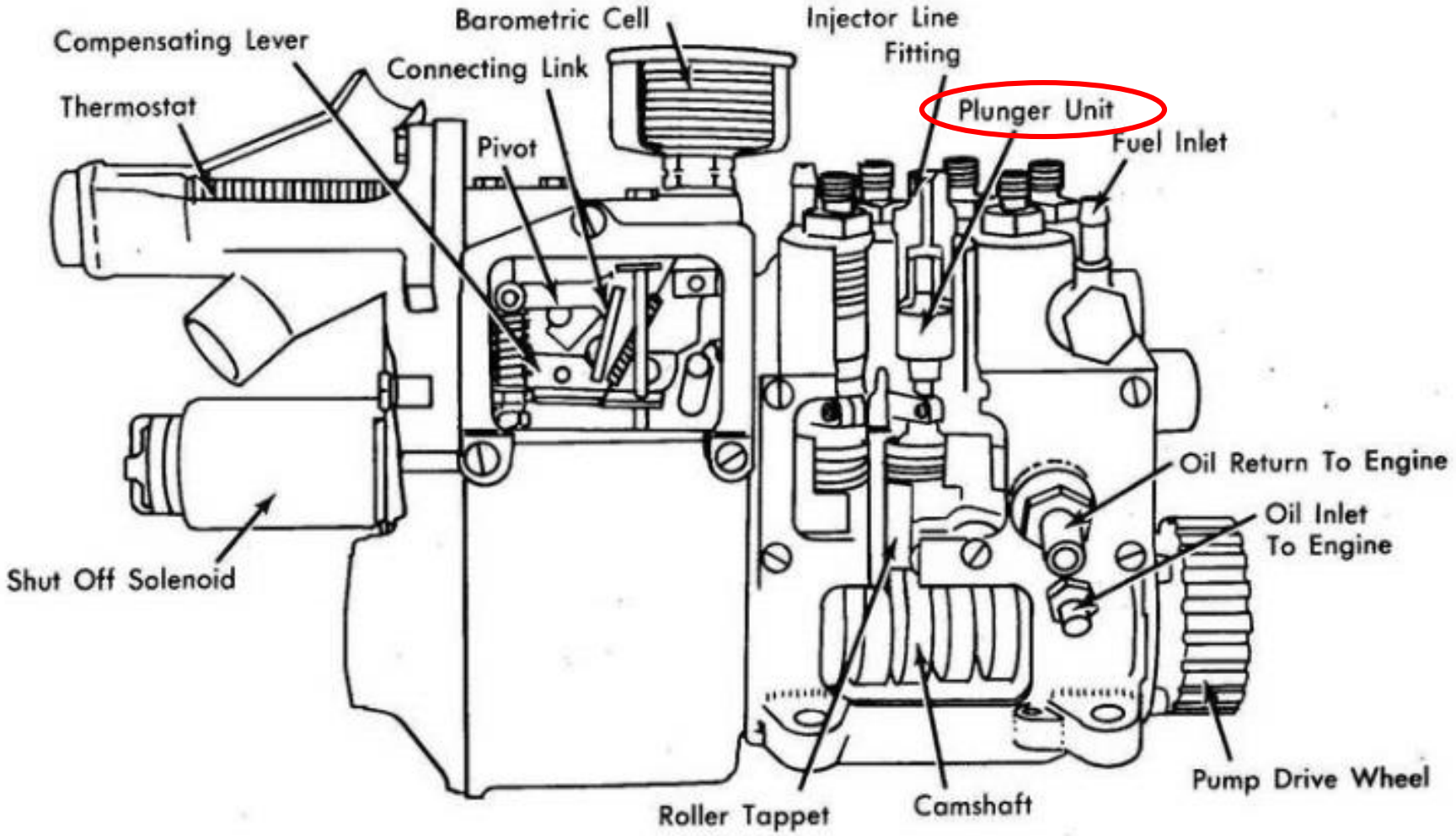


Figure 3

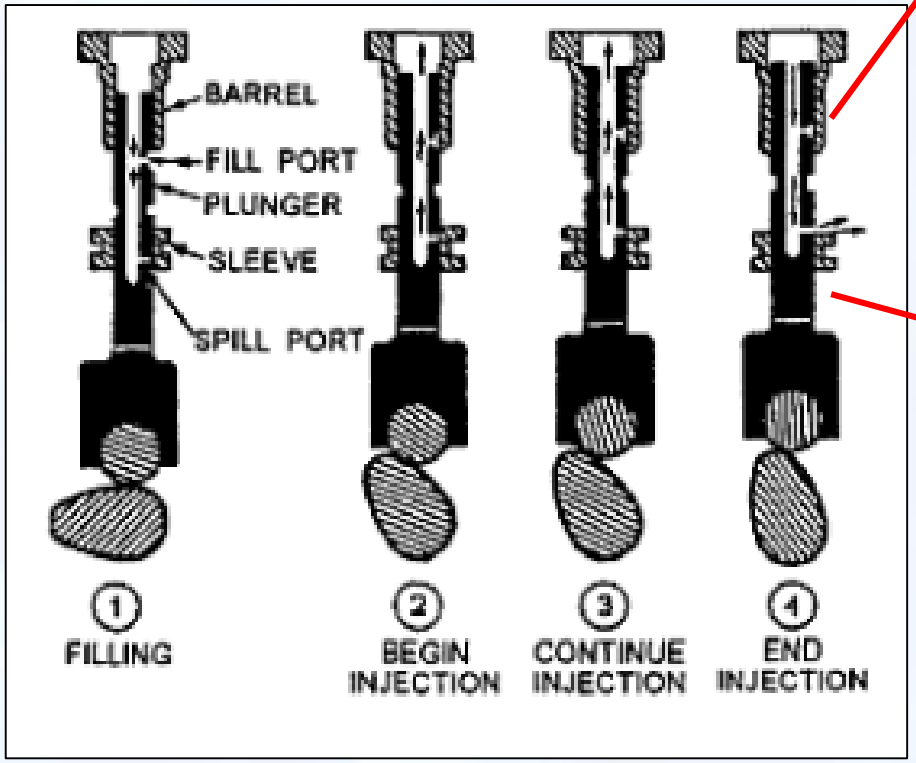
1 Thermostat
2 Compensating lever
3 Thermostat connecting sleeve
4 Cross-arm
5 Support
6 Guide stud
7 Barometric cell
8 Guide
9 Injector line fitting
10 Check valve
11 Plunger unit
12 Fuel inlet
13 Toothed segment
14 Plunger spring
15 Engine oil return
16 Engine oil inlet
17 Pump drive wheel
18 Support flange
19 Camshaft
20 Roller tappet
21 Contoured cam spring
22 Contoured cam
23 Sensor
24 Centrifugal governor weight
25 Idle speed adjustment
26 Shut-off solenoid
27 Access to control rack head
28 Enrichment solenoid

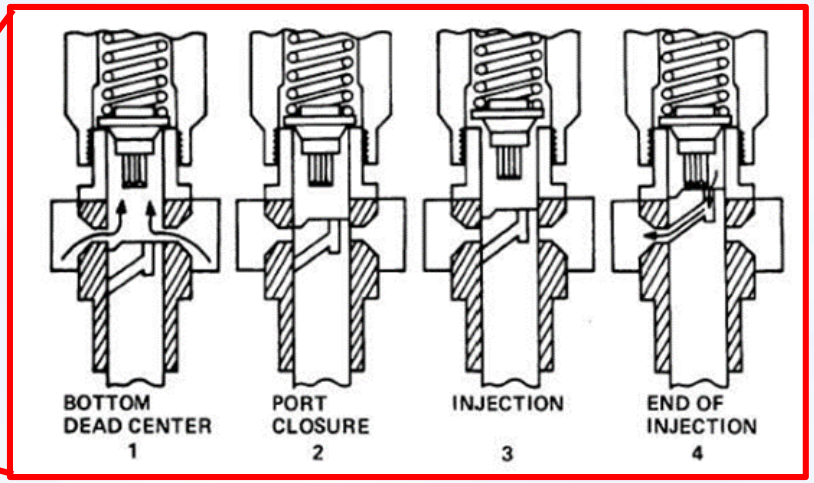
Bosch Mechanical Fuel Injection

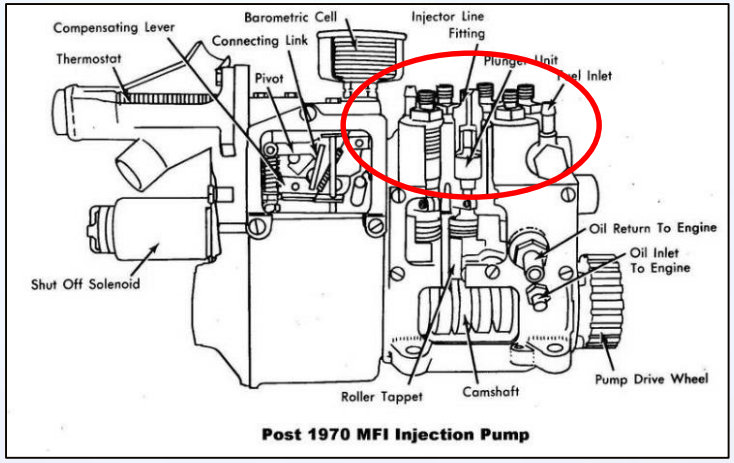


Post 1970 MFI Injection Pump

Bosch Mechanical Fuel Injection

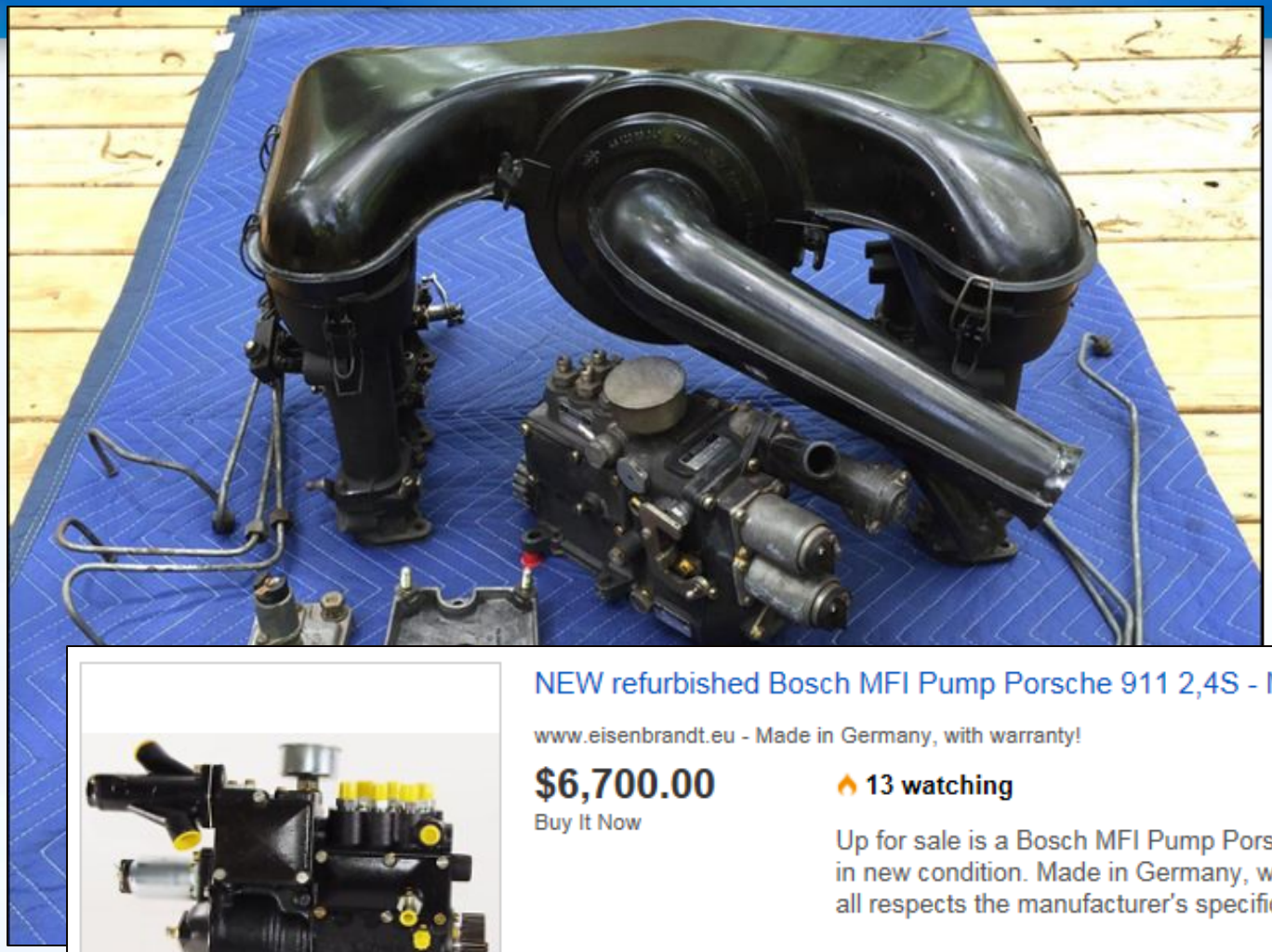






Post 1970 MFI Injection Pump

Bosch Mechanical Fuel Injection



NEW refurbished Bosch MFI Pump Porsche 911 2,4S - Mechanical Fuel Injection

www.eisenbrandt.eu - Made in Germany, with warranty!

$6,700.00

Buy It Now

13 watching

Up for sale is a Bosch MFI Pump Porsche 911 2,4S. This MFI Pump is in new condition. Made in Germany, with warranty! The pump meets in all respects the manufacturer's specification.

Item condition: **Used**

Time left: 4d 02h Sunday, 3:15PM

Price: **US $6,950.00**
From $334 for 24 months

Buy It Now

Continuous Injection System CIS

Bosch K-Jetronic

CIS Injector Type

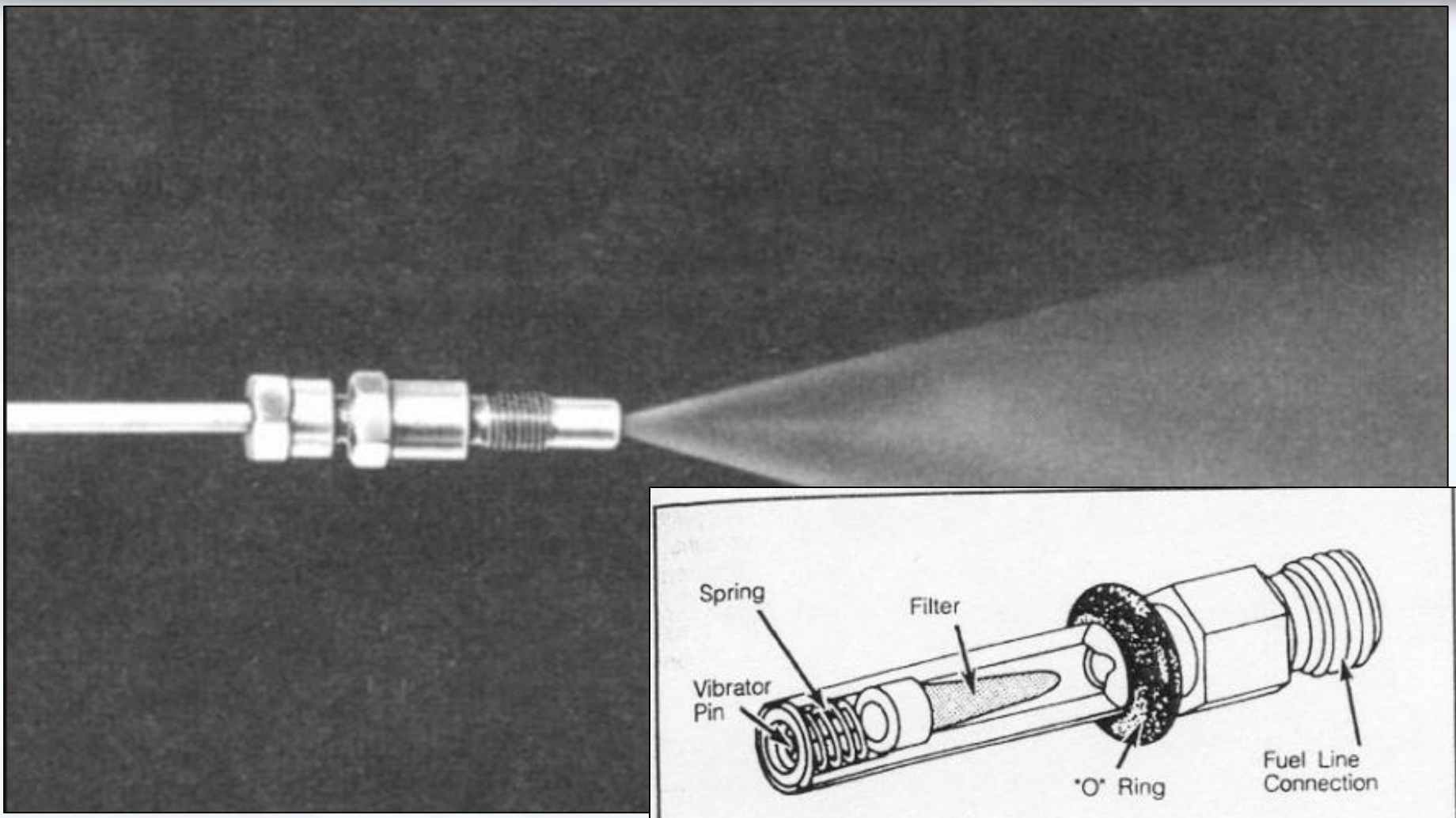
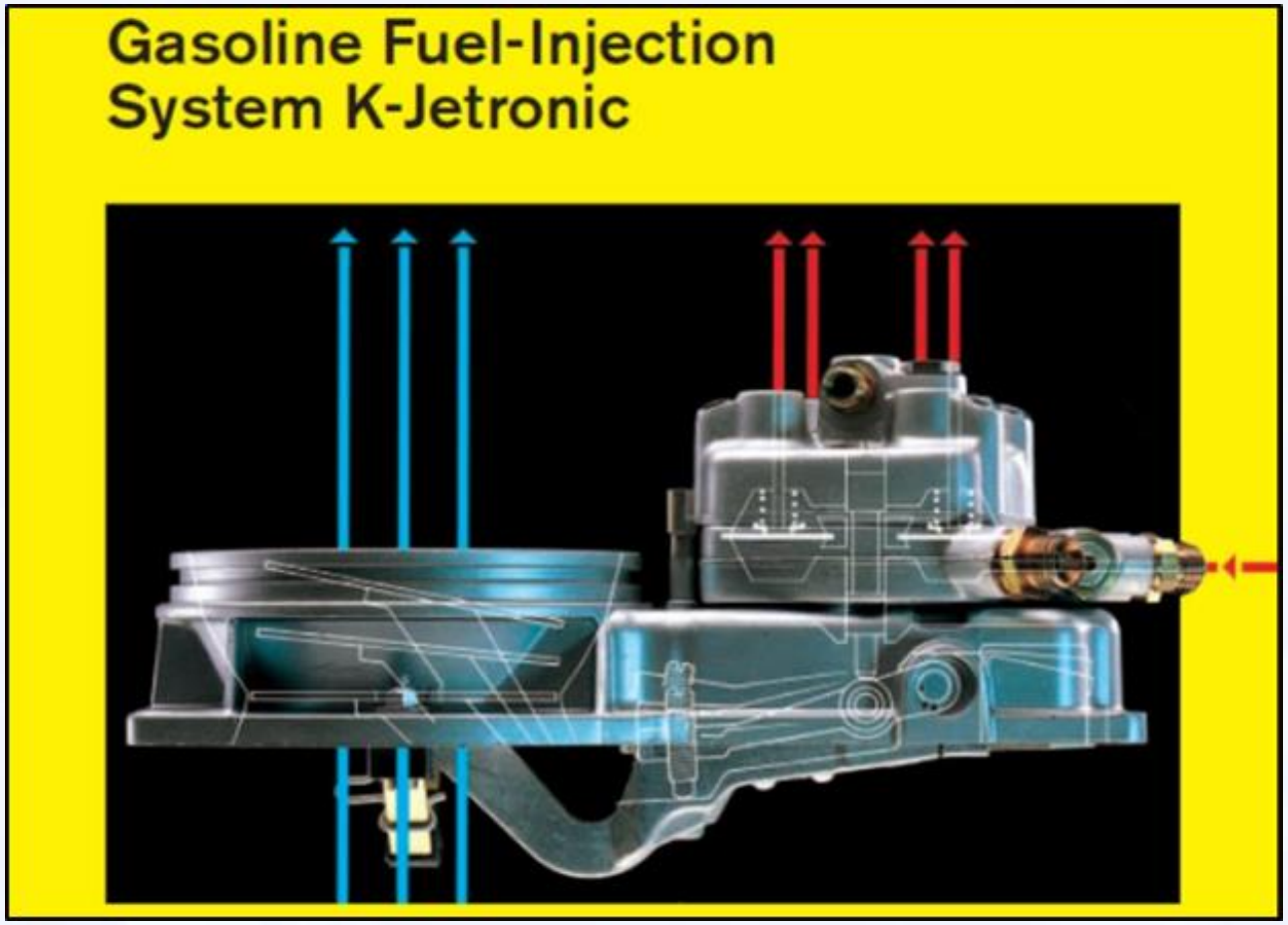
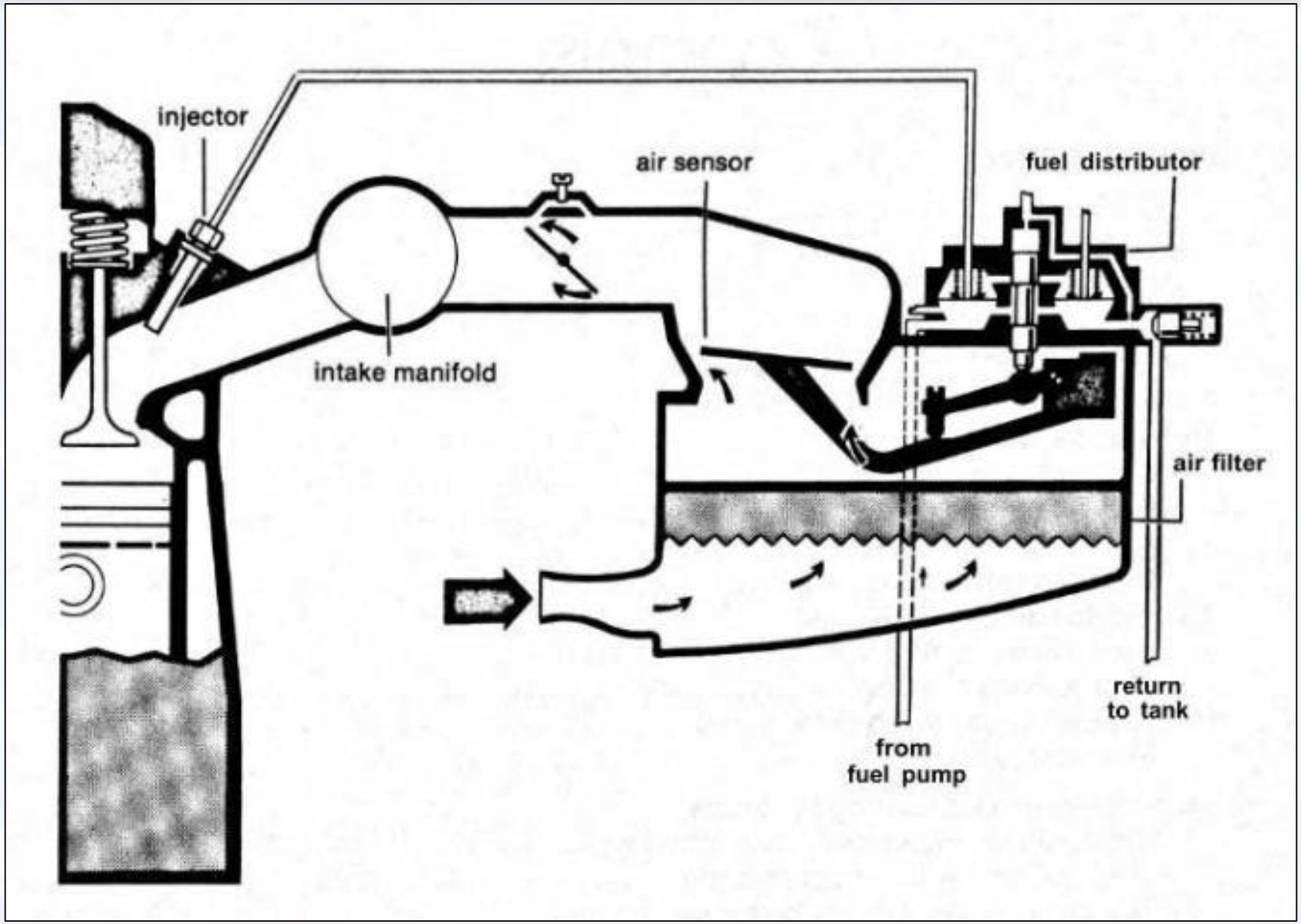


Fig. 11: Bosch CIS Injector

Bosch CIS (K-Jetronic)



Bosch CIS (K-Jetronic)



Bosch CIS (K-Jetronic)

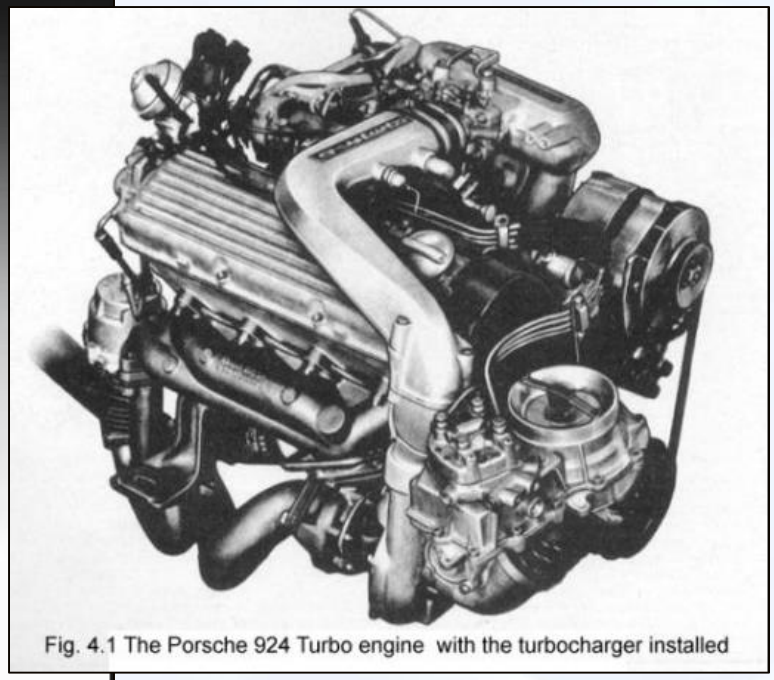
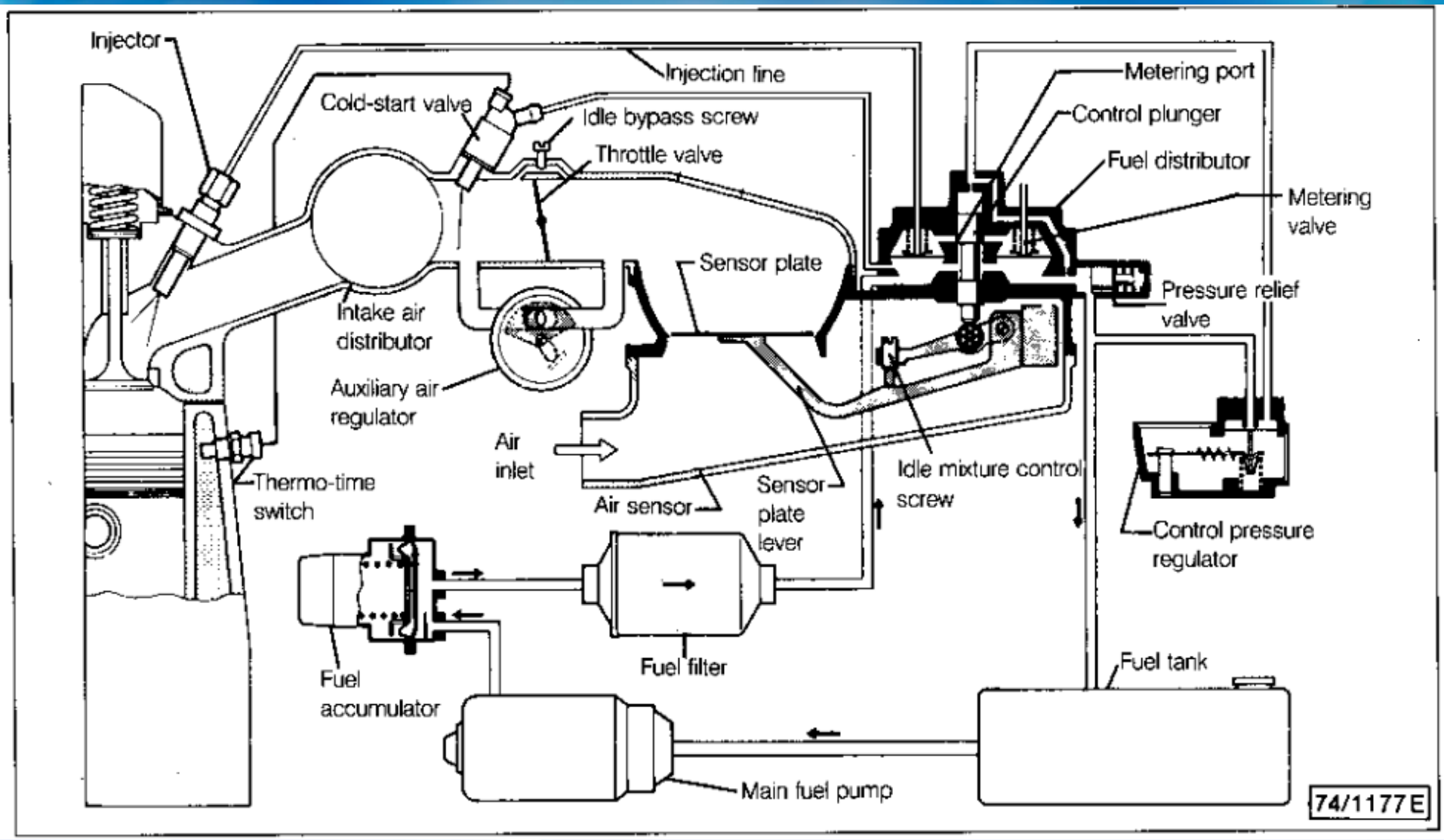
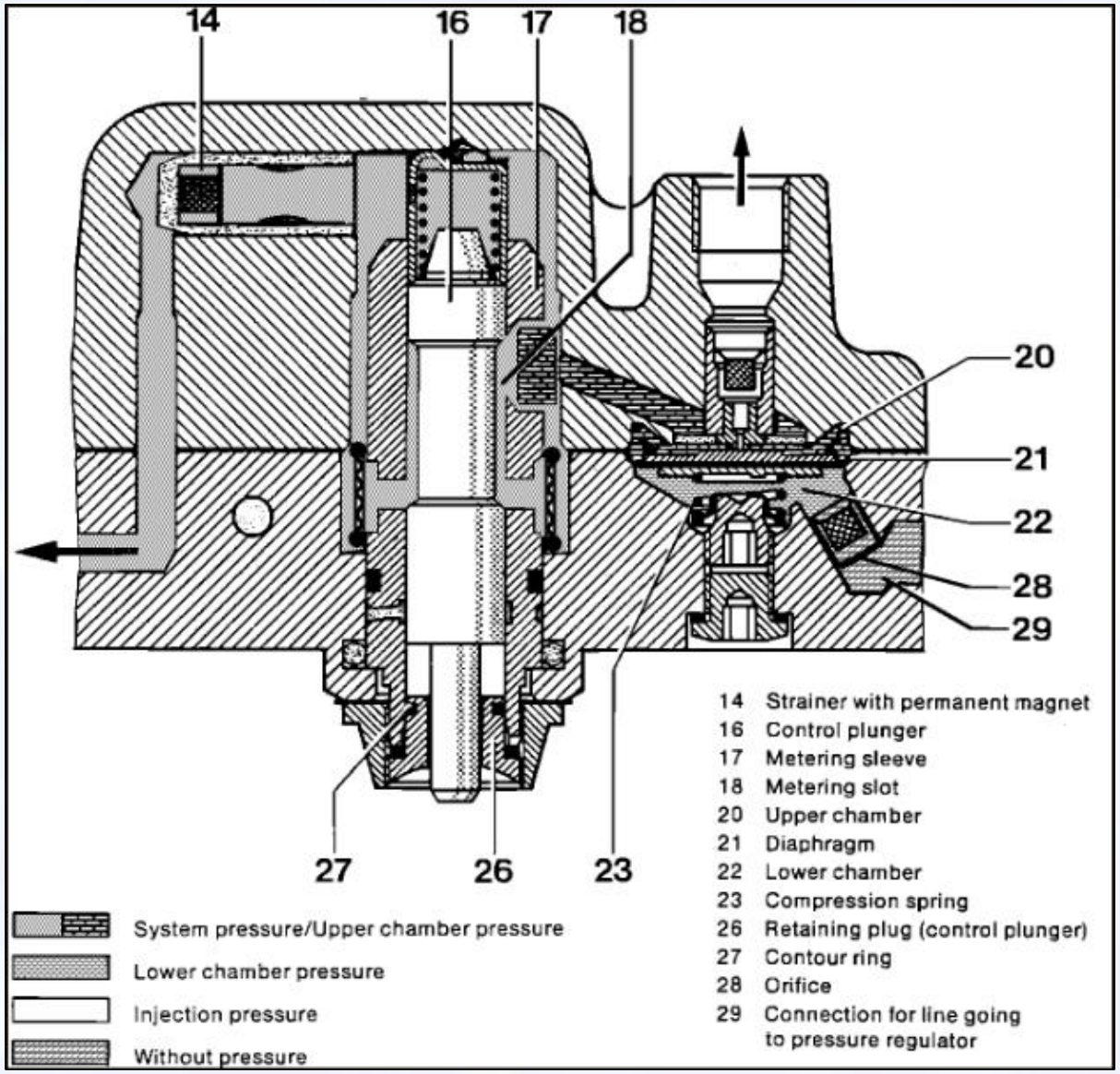


Fig. 4.1 The Porsche 924 Turbo engine with the turbocharger installed

Bosch CIS (K-Jetronic)



Bosch CIS (K-Jetronic)

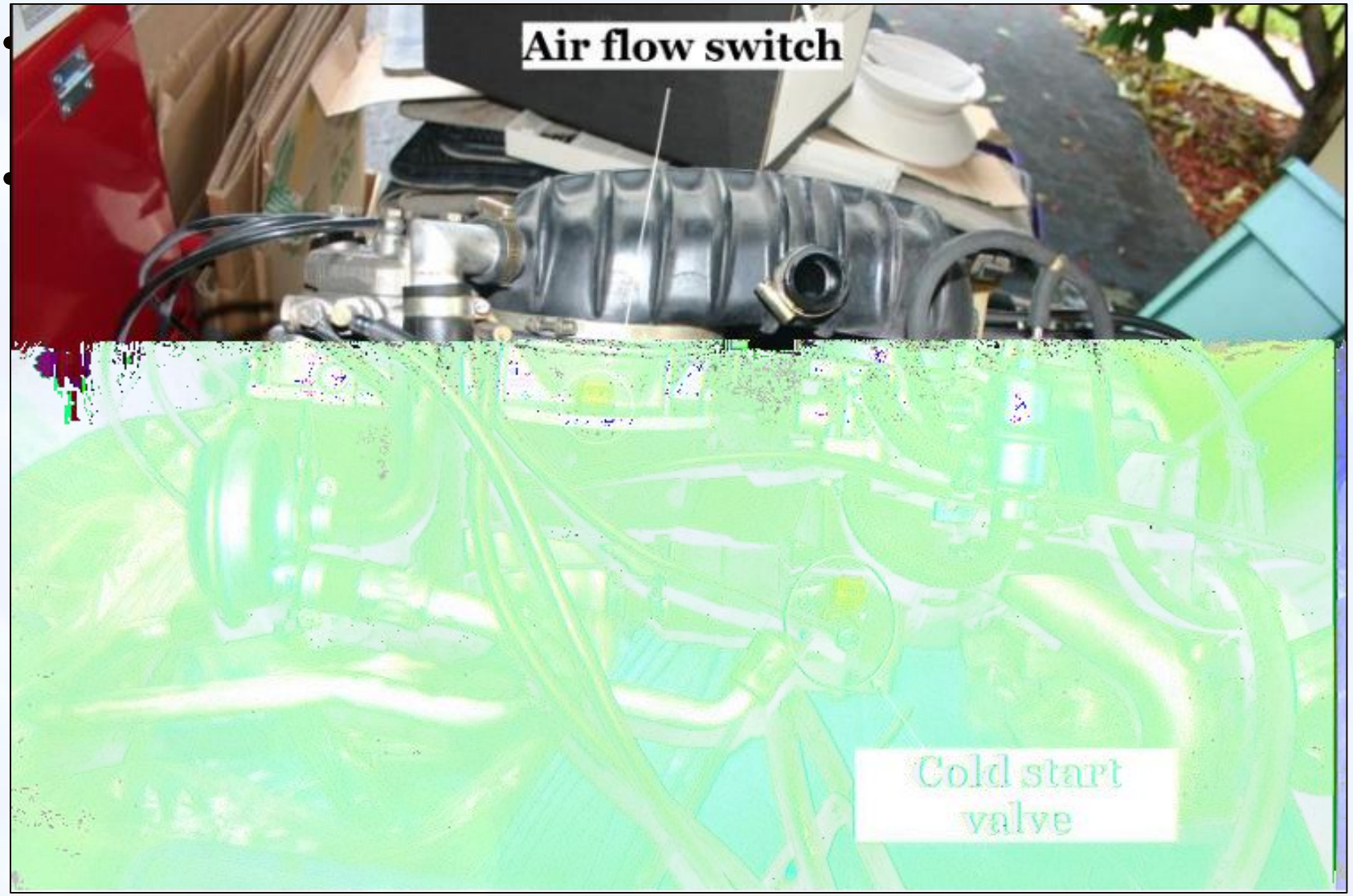


Rube would be proud.

Bosch CIS (K-Jetronic)

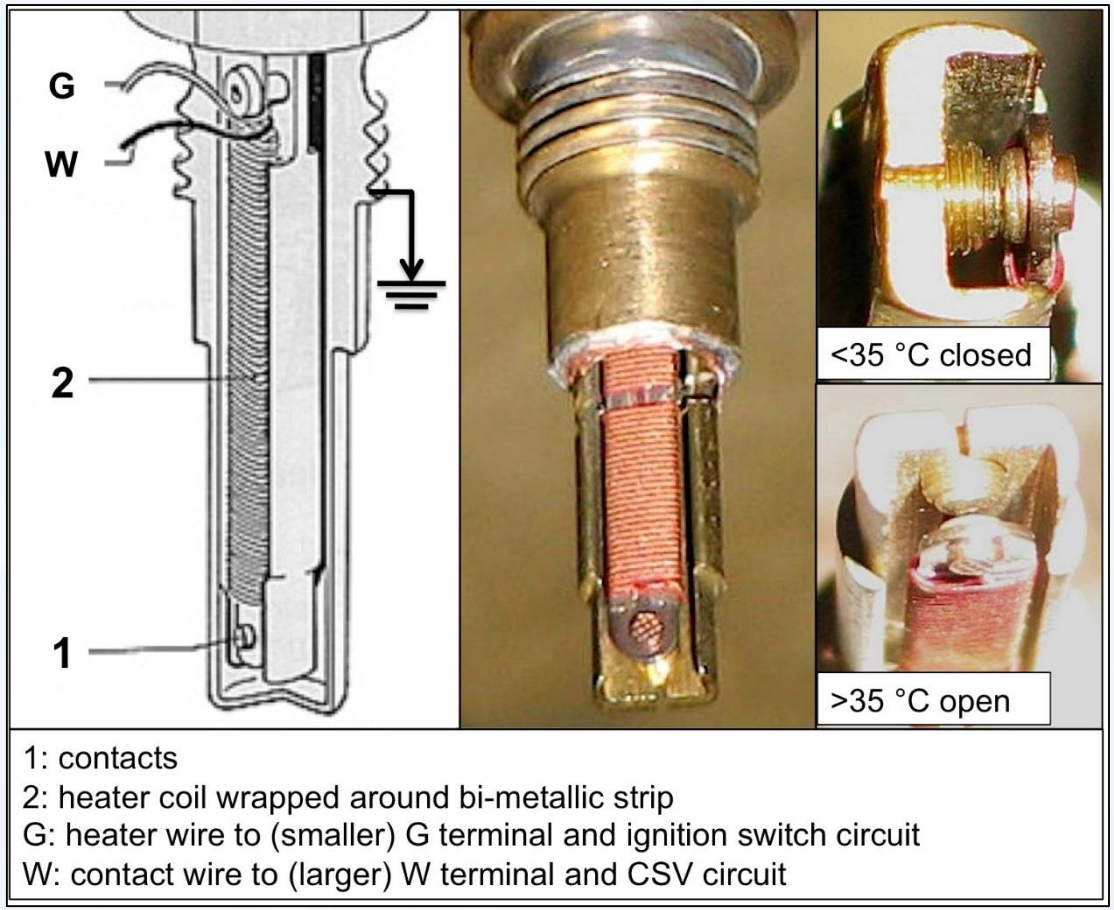
A first-generation electro-magnetic fuel injector is used to add additional fuel for start-up. This proved problematic for some 911 air boxes as fuel would pool at the bottom of the intake plenum.

Bosch CIS (K-Jetronic)



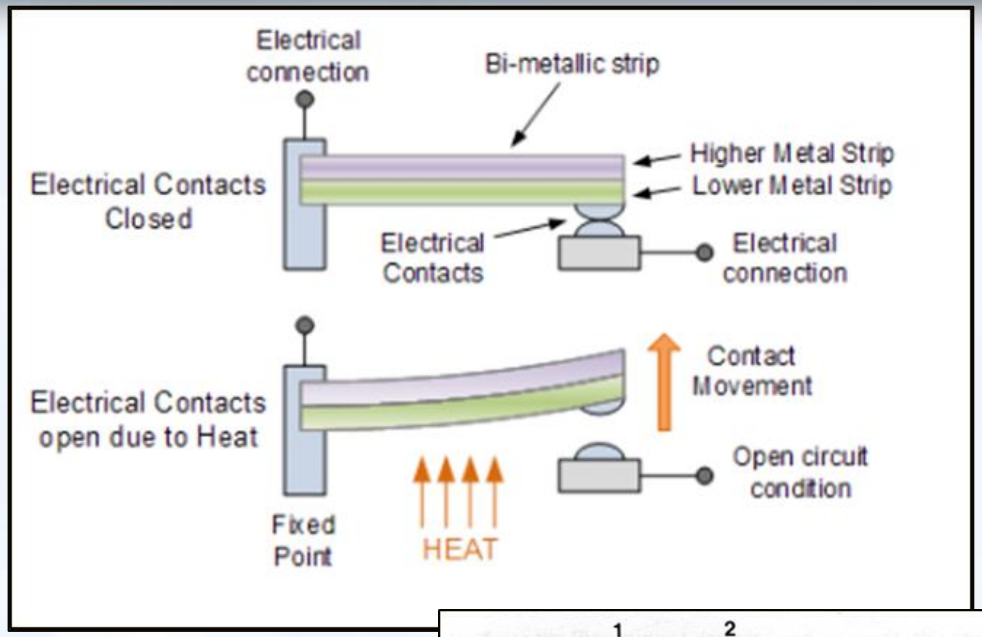
Bosch CIS (K-Jetronic)

We're introduced to a combination of simple sensors that use resistors and bi-metallic strips to sense temperature and activate cold starting and cold running cycles.

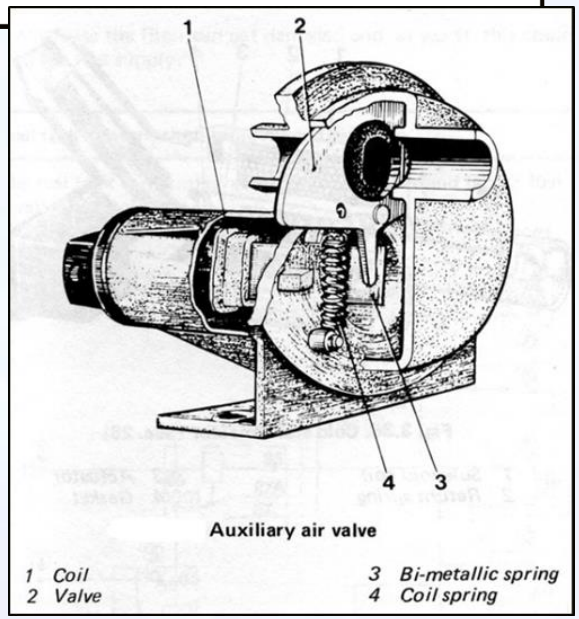


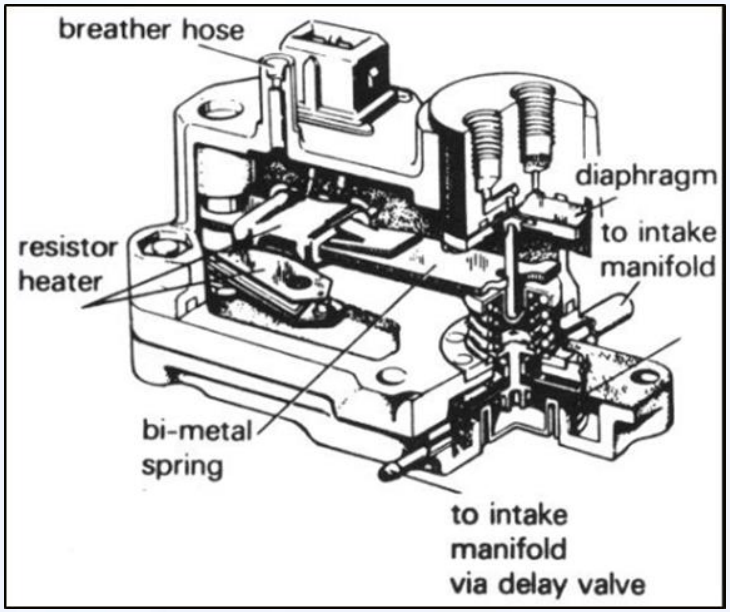
1: contacts
2: heater coil wrapped around bi-metallic strip
G: heater wire to (smaller) G terminal and ignition switch circuit
W: contact wire to (larger) W terminal and CSV circuit

Bosch CIS (K-Jetronic)



Bi-metal strips can open and close contacts, and can even be leveraged to perform work, as in the aux. air valve and warmup regulator.

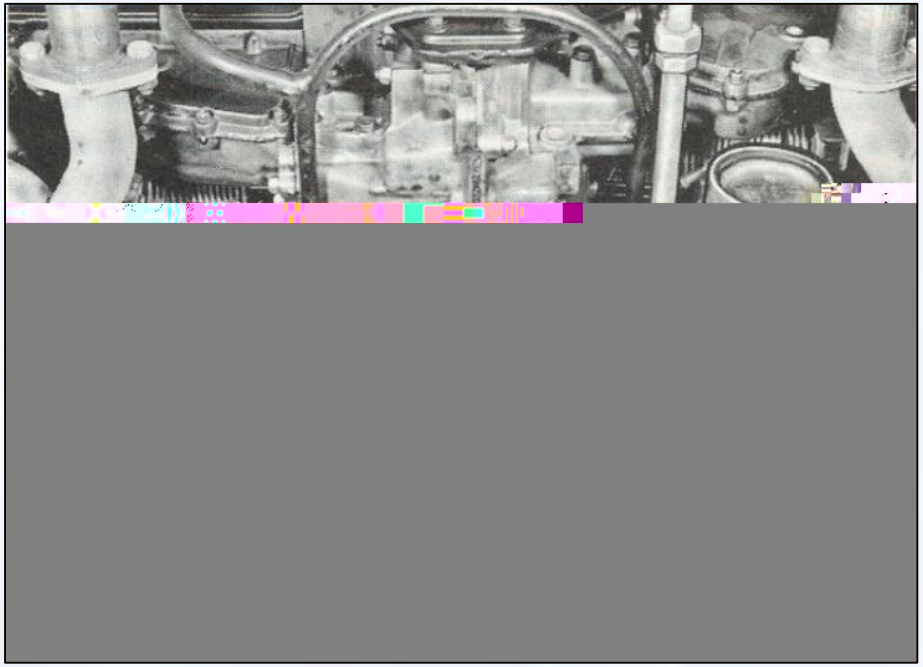


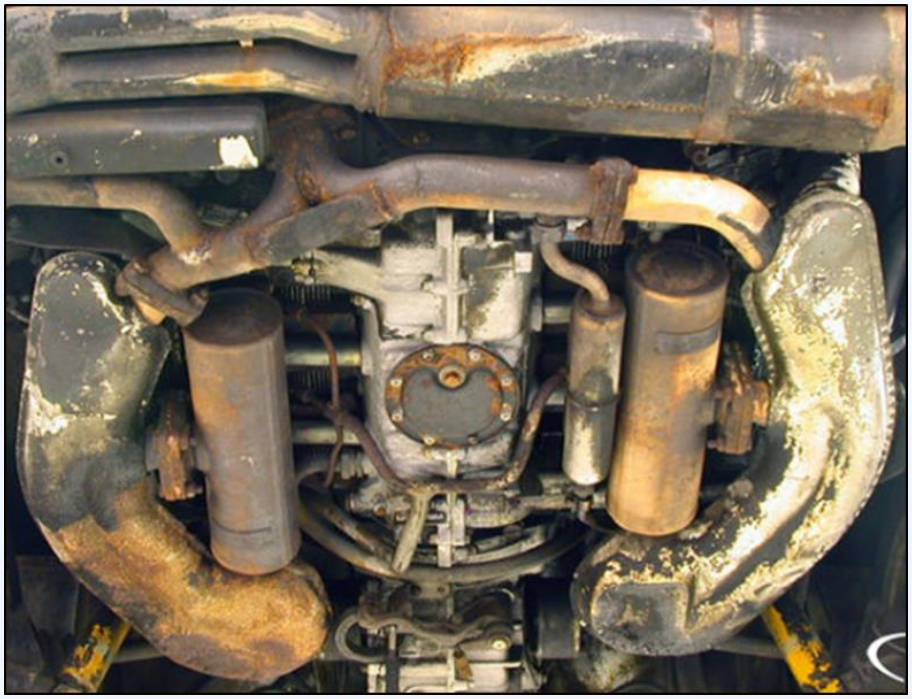


Time Out!

Let's recognize other fuel-related components

Auxiliary Air Injection (even Thermo Reactors!)
Catalytic Converters
Oxygen Sensors (non-heated, heated, pre- and post-catalyst)
Fuel Vapor Recovery including the Charcoal Canister & Expansion Tanks
Crankcase ventilation, including air/oil separators

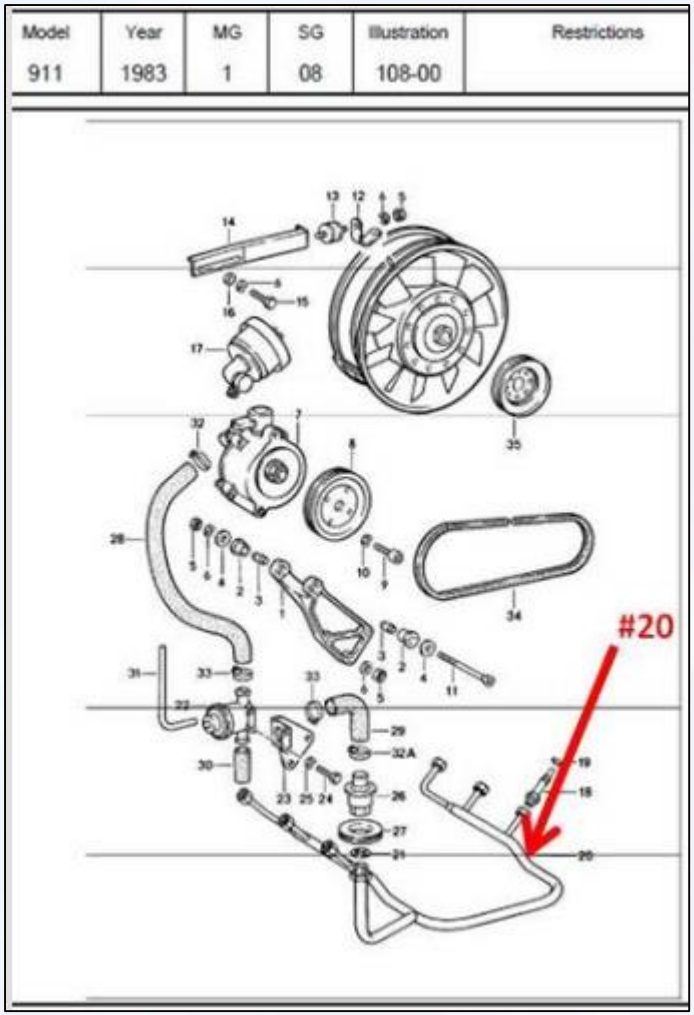




Time Out!

Let’s recognize other fuel-related components:

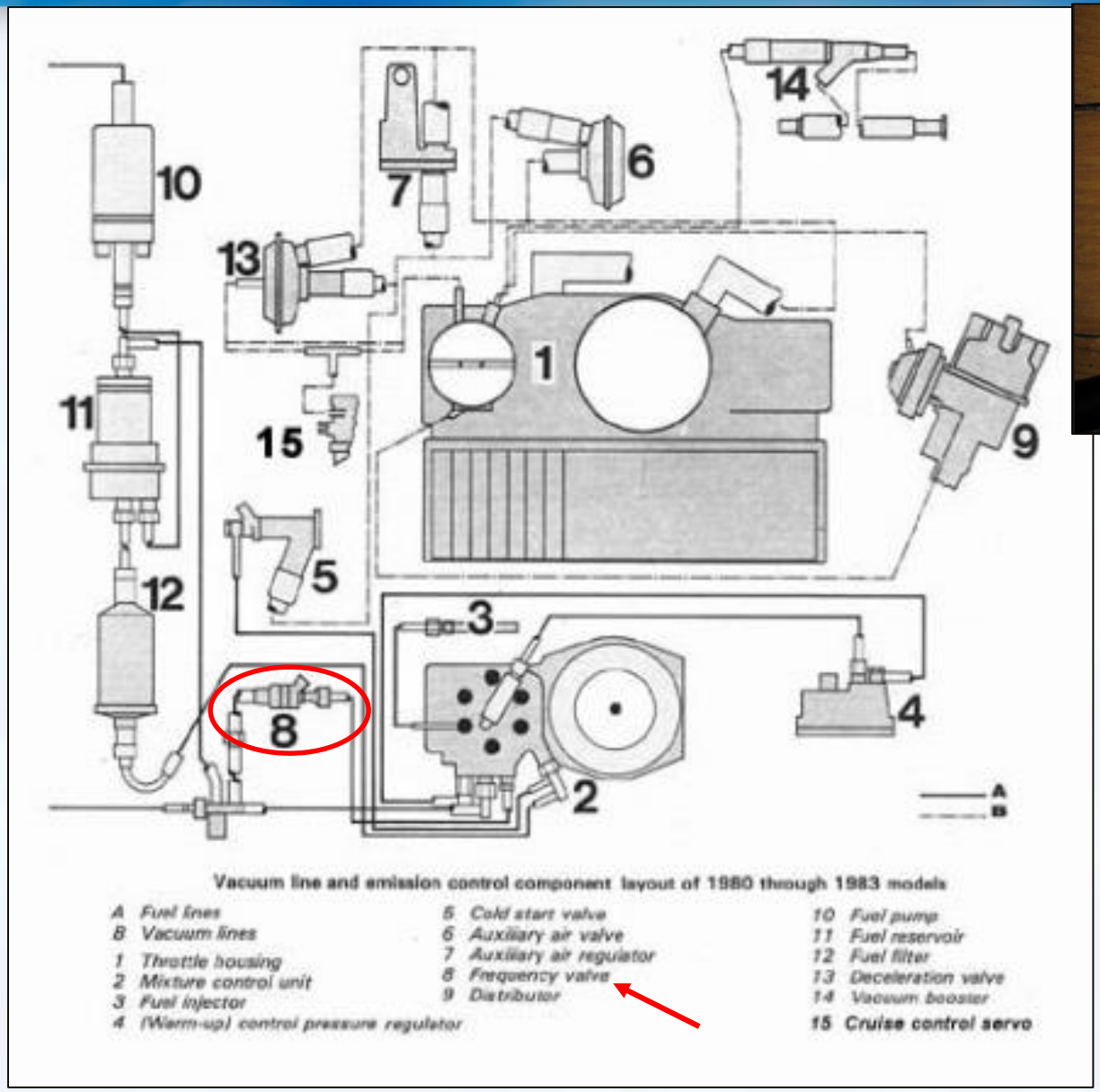
Auxiliary Air Injection with Thermo Reactors



Think About It

"Blind" fuel injection systems vs.
"Smart(er)" fuel injection systems:
Q: What's the difference?
A: Some level of feedback.

Bosch CIS with Lambda Control

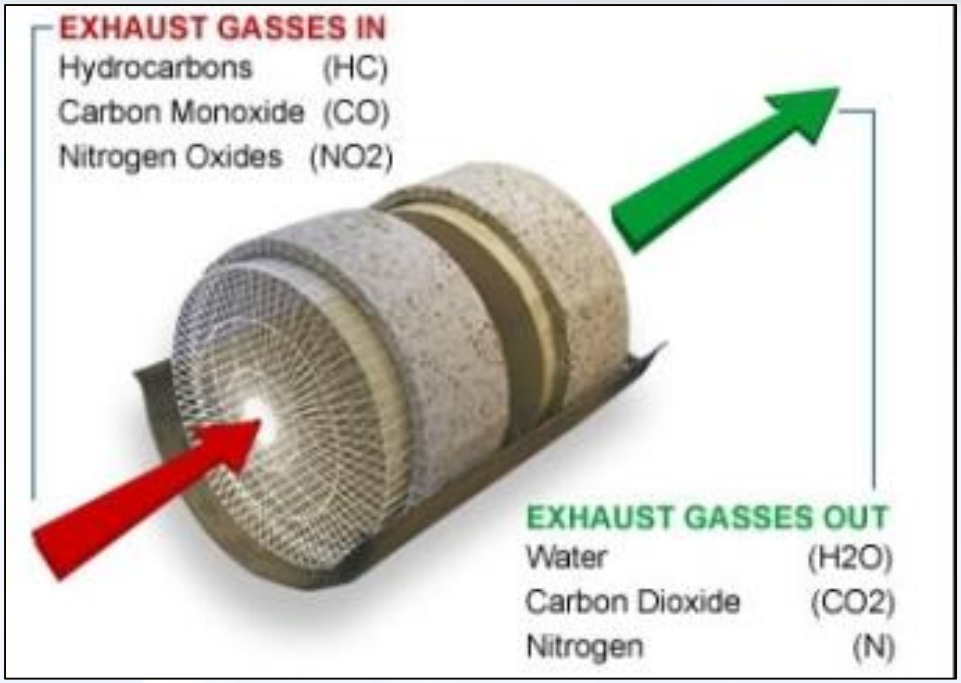


Vacuum line and emission control component layout of 1980 through 1983 models

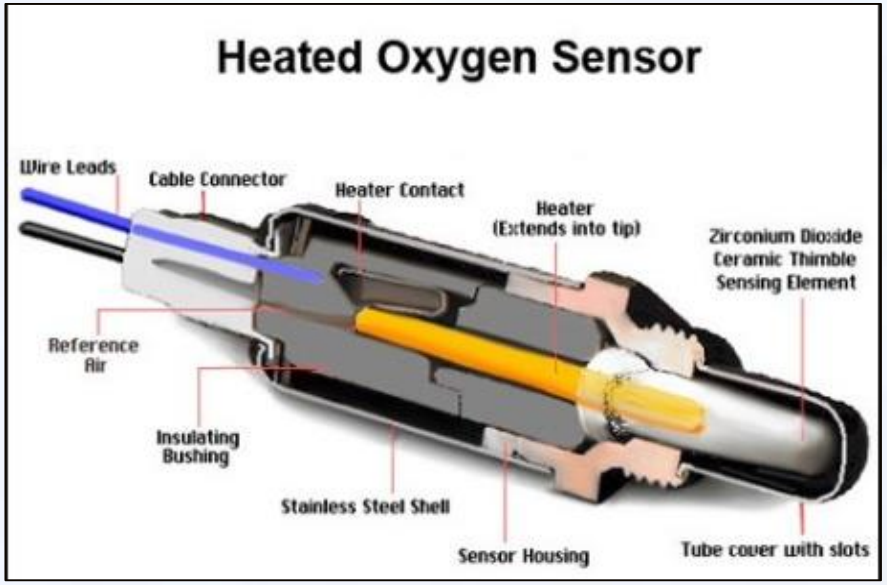
A Fuel lines
B Vacuum lines
1 Throttle housing
2 Mixture control unit
3 Fuel injector
4 (Warm-up) control pressure regulator
5 Cold start valve
6 Auxiliary air valve
7 Auxiliary air regulator
8 Frequency valve
9 Distributor
10 Fuel pump
11 Fuel reservoir
12 Fuel filter
13 Deceleration valve
14 Vacuum booster
15 Cruise control servo

"Lambda Control"

Catalytic Converters Introduced

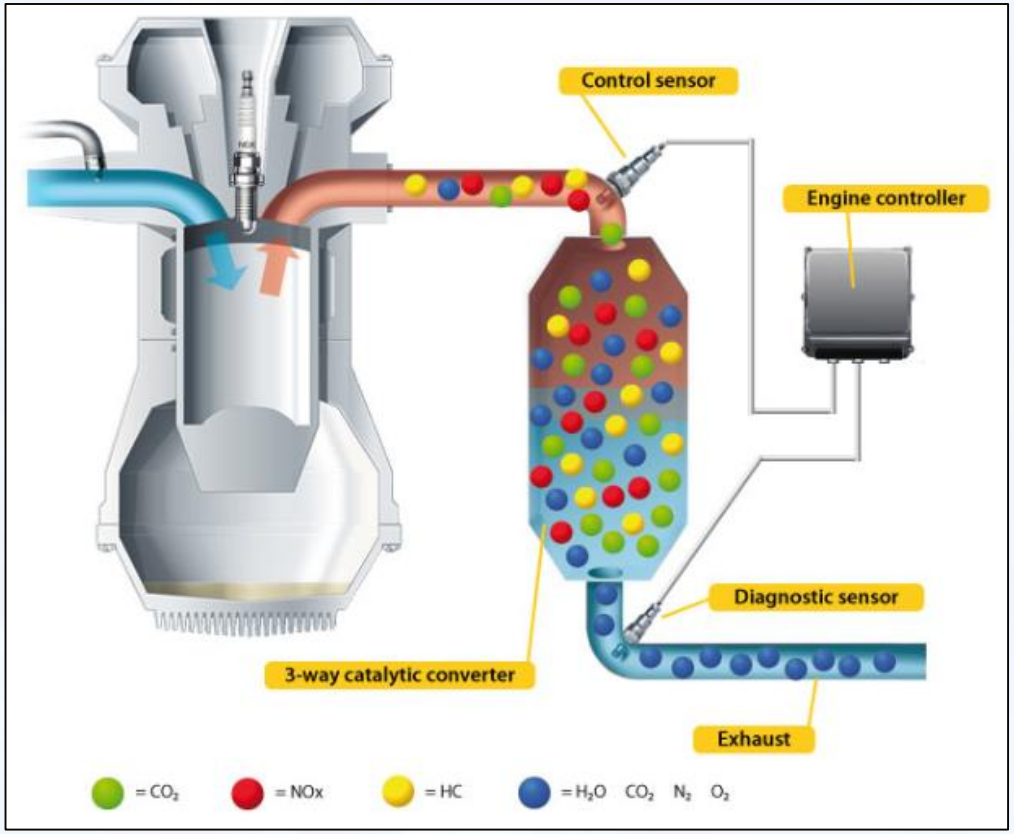


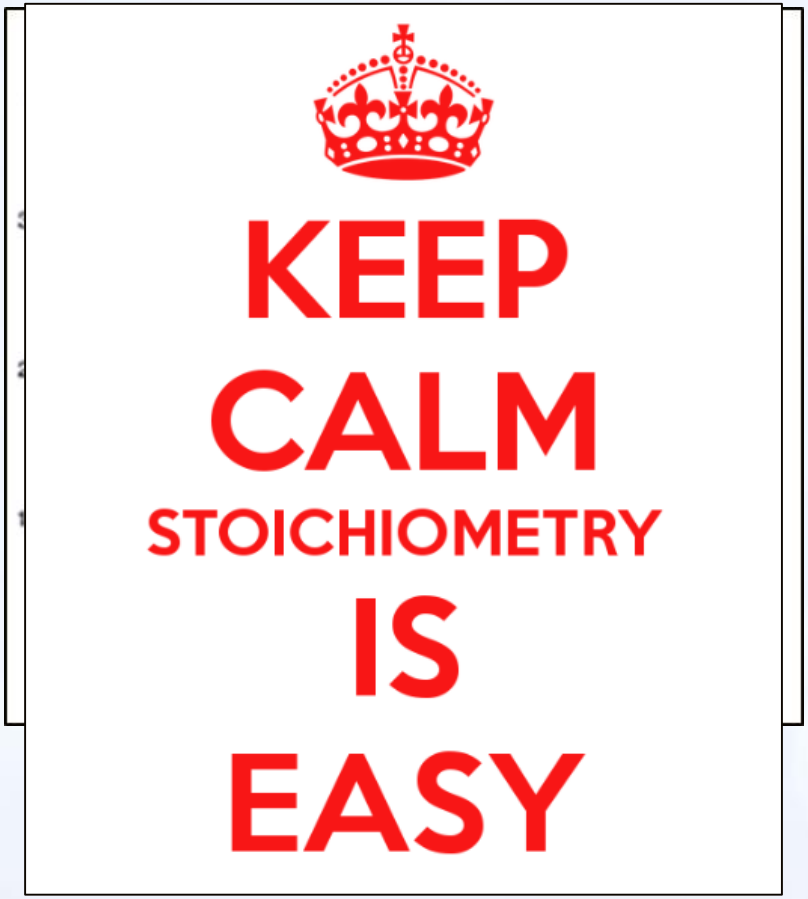
Oxygen sensors are used not only to keep the engine running properly, they also help prevent the catalyst from overheating by limiting hydrocarbons



Catalytic Converters Introduced

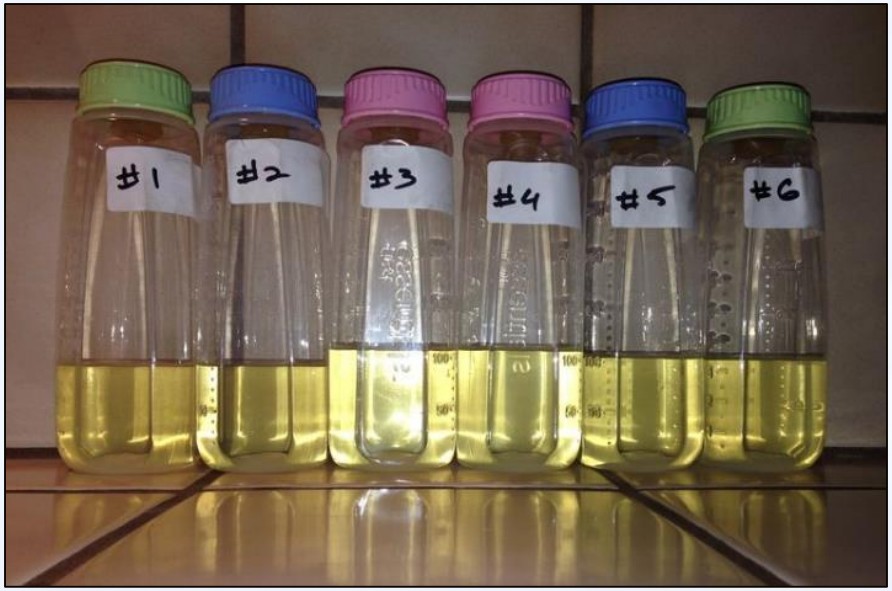
The oxygen sensor serves multiple functions today, targeting the best running condition of the engine, and evaluating the health of the catalyst



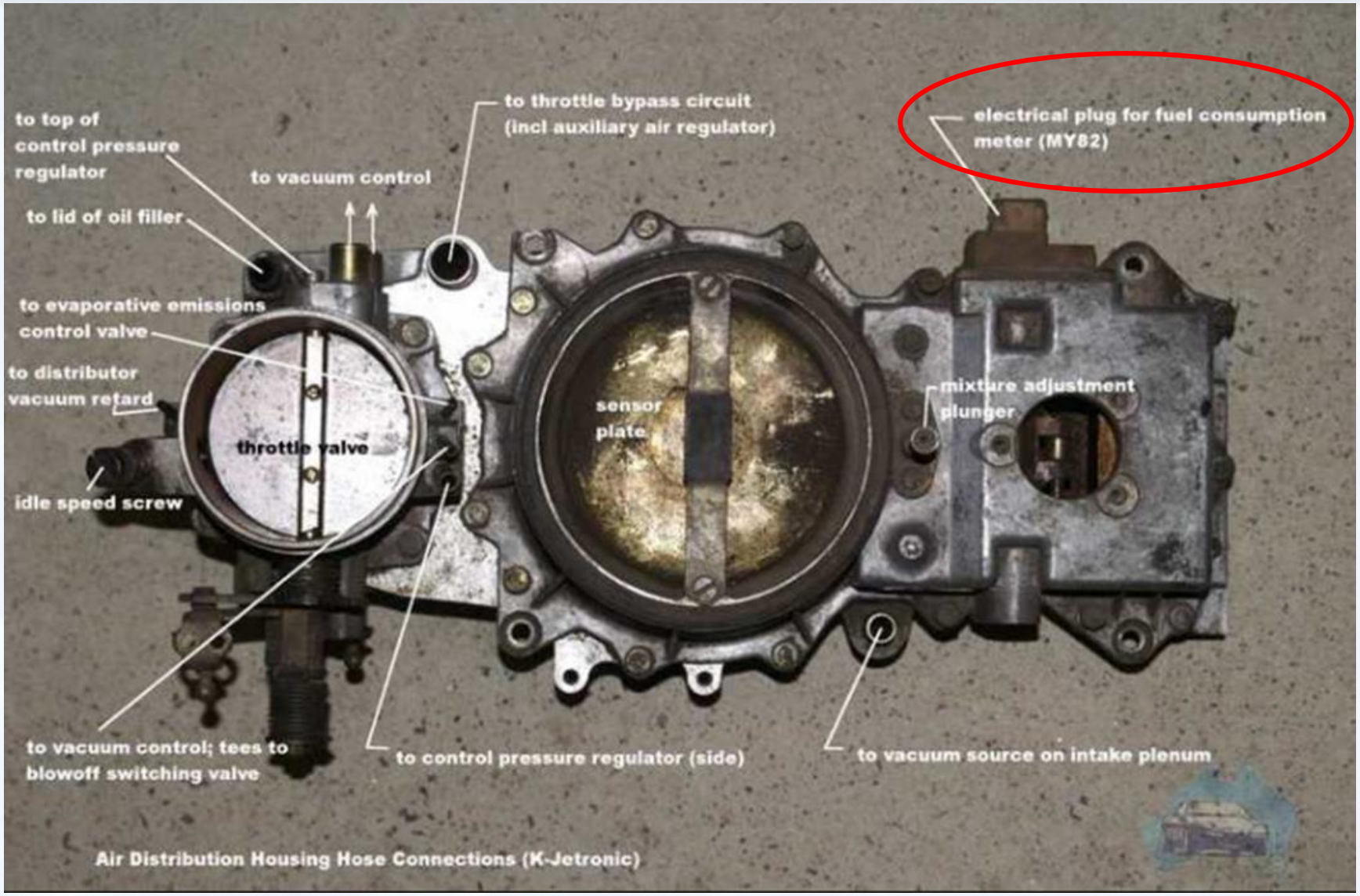


Fundamental Challenges with K-Jetronic

As good as the fuel distributor/fuel injector setup was, there tended to be differences in fuel delivery to each cylinder



Bosch CIS (K-Jetronic)



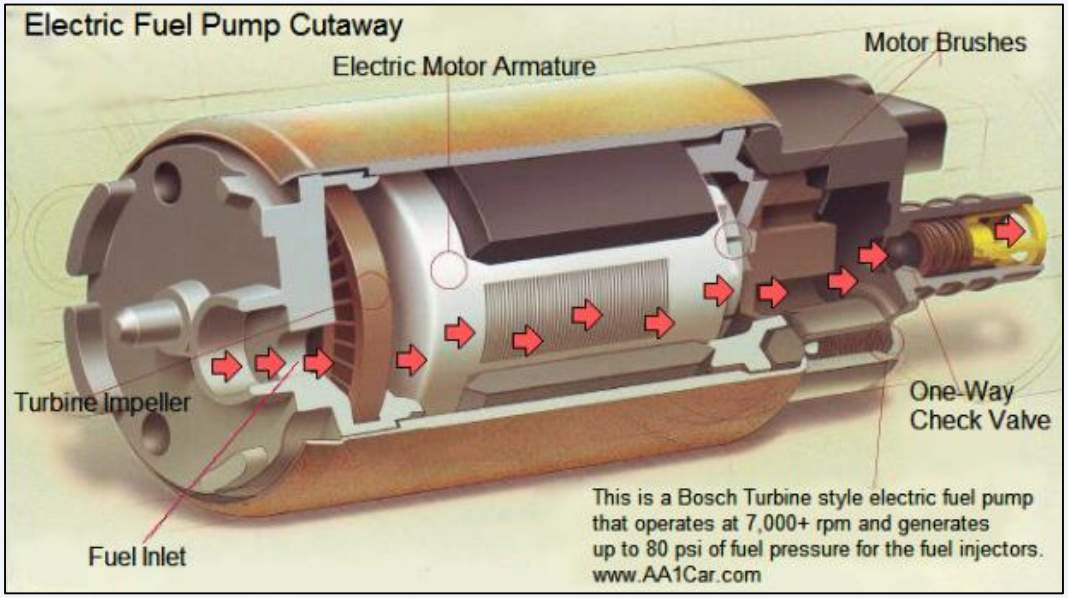
Time Out!

Let's focus on a component: Fuel Pump

Porsche 911 Turbo S 01-05 Fuel Pump In Tank

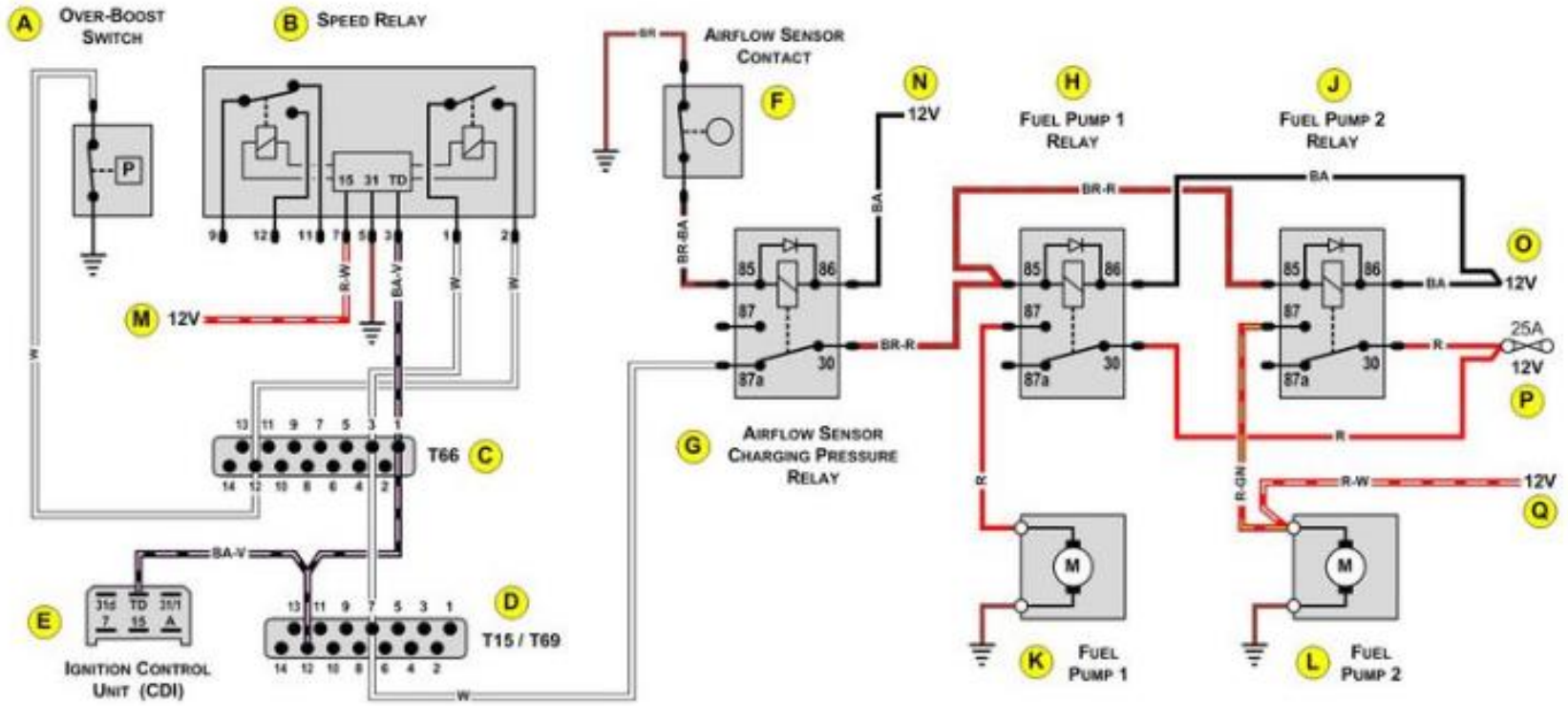
Q: What cools the pump?

A: Gasoline!

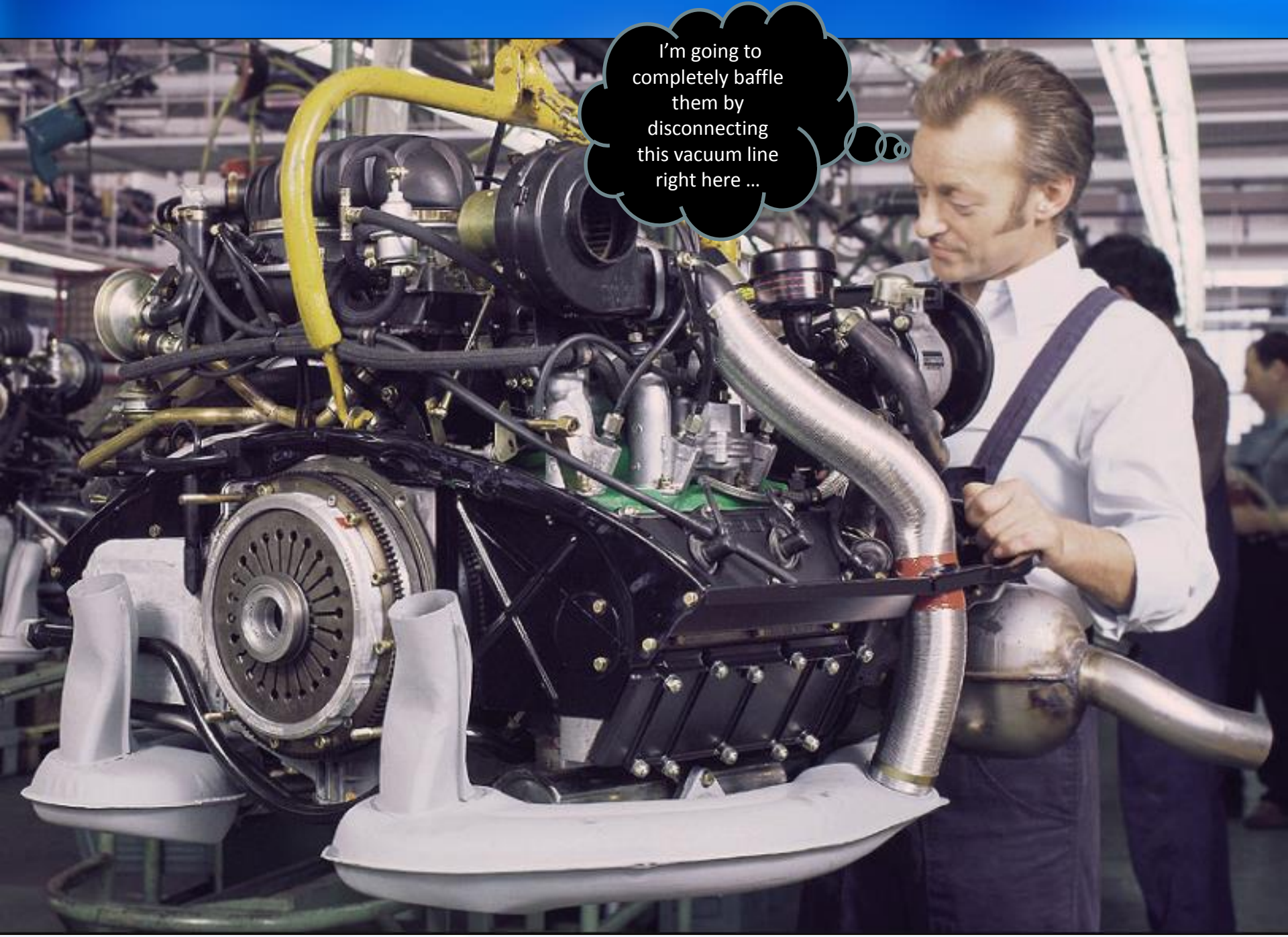


And you want the fuel pump to run?

WIRING DIAGRAM - FUEL SYSTEM – 1986 TURBO 930



- A Switch mounted on BOV housing or after-market intercooler (930.606.101.00)
- B Relay mounted under LH seat (930.618.123.00)
- C 14 pin connector on cross-member in front of engine LHS (AKA T66)
- D 14 pin connector on engine bay relay panel (AKA T69 and T15)
- E Control unit mounted on engine bay relay panel (930.602.702.X) (AKA CDI)
- F Switch mounted front of airflow meter (911.110.929.00) (AKA safety contact)
- G Relay mounted on engine bay relay panel behind yellow relay (911.615.109.01)
- H Relay mounted second rear-most at front fuse box (911.615.108.01)
- J Relay mounted rear-most at front fuse box (911.615.108.01)
- K Pump mounted behind steering rack (911.608.102.02)
- L Pump mounted above LH rear sway bay mount (930.608.113.00)
- M 12V power supply from inlet side of fuse box 1, 12V with ignition on *(Ignition 15)*
- N 12V power supply from inlet side of fuse box 1, 12V with ignition on *(Ignition X)*
- O 12V power supply from inlet side of fuse box 1, 12V with ignition on *(Ignition 15)*
- P 12V power supply from battery via fuse box 1, 25A fuse #3 *(Ignition 30)*
- Q 12V to Warm-Up Regulator (WUR)


I’m going to completely baffle them by disconnecting this vacuum line right here …

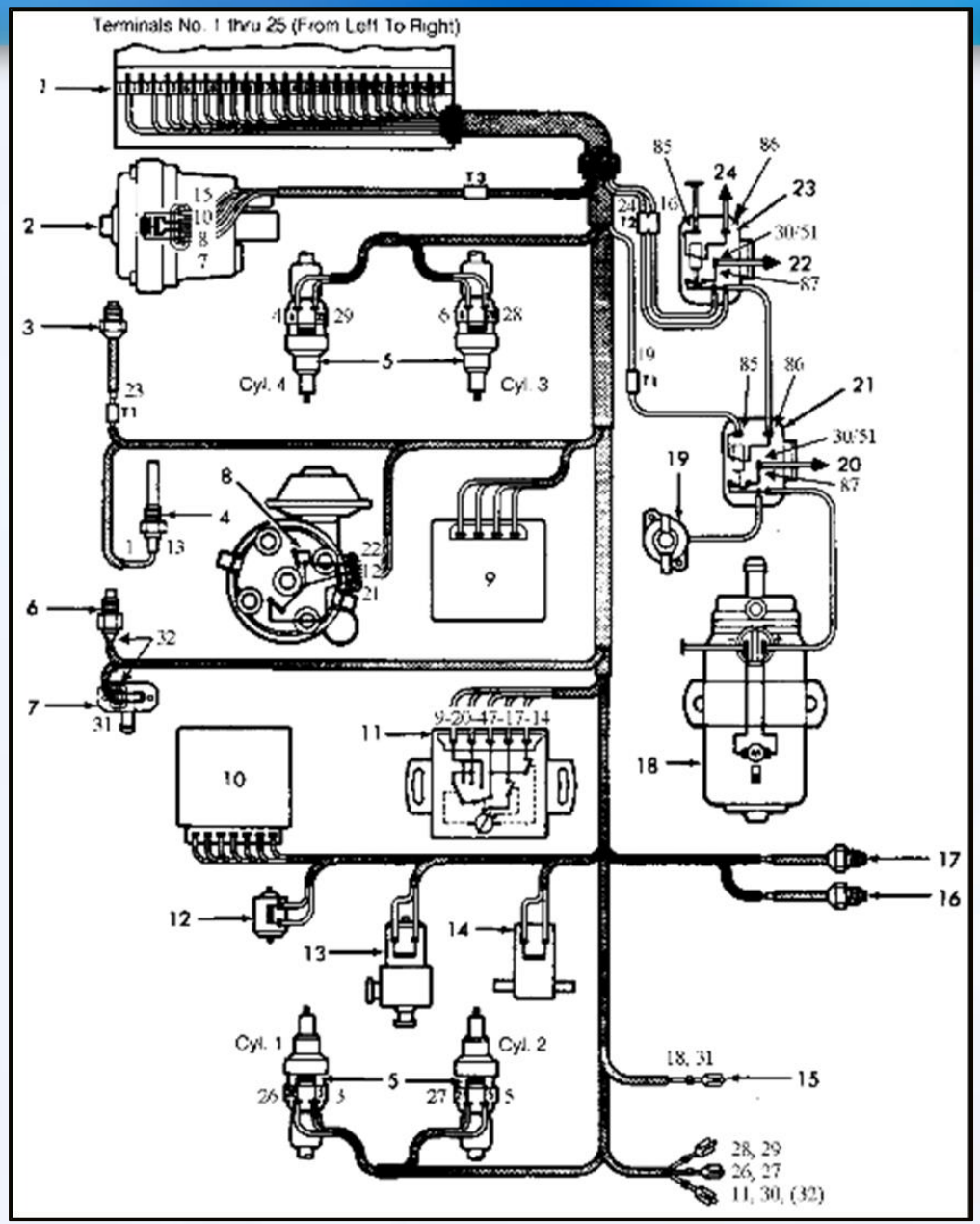
Manifold Pressure Injection MPI

Bosch D-Jetronic

Bosch MPI (D-Jetronic)

Fundamentally different than CIS and much closer to our current generation fuel systems:

- Uses a microprocessor control unit to activate the injectors
- Solenoid-style electric injectors
- Utilizes a throttle switch with multiple internal contacts
- The big news is that it determines engine load by means of a vacuum sensing unit.

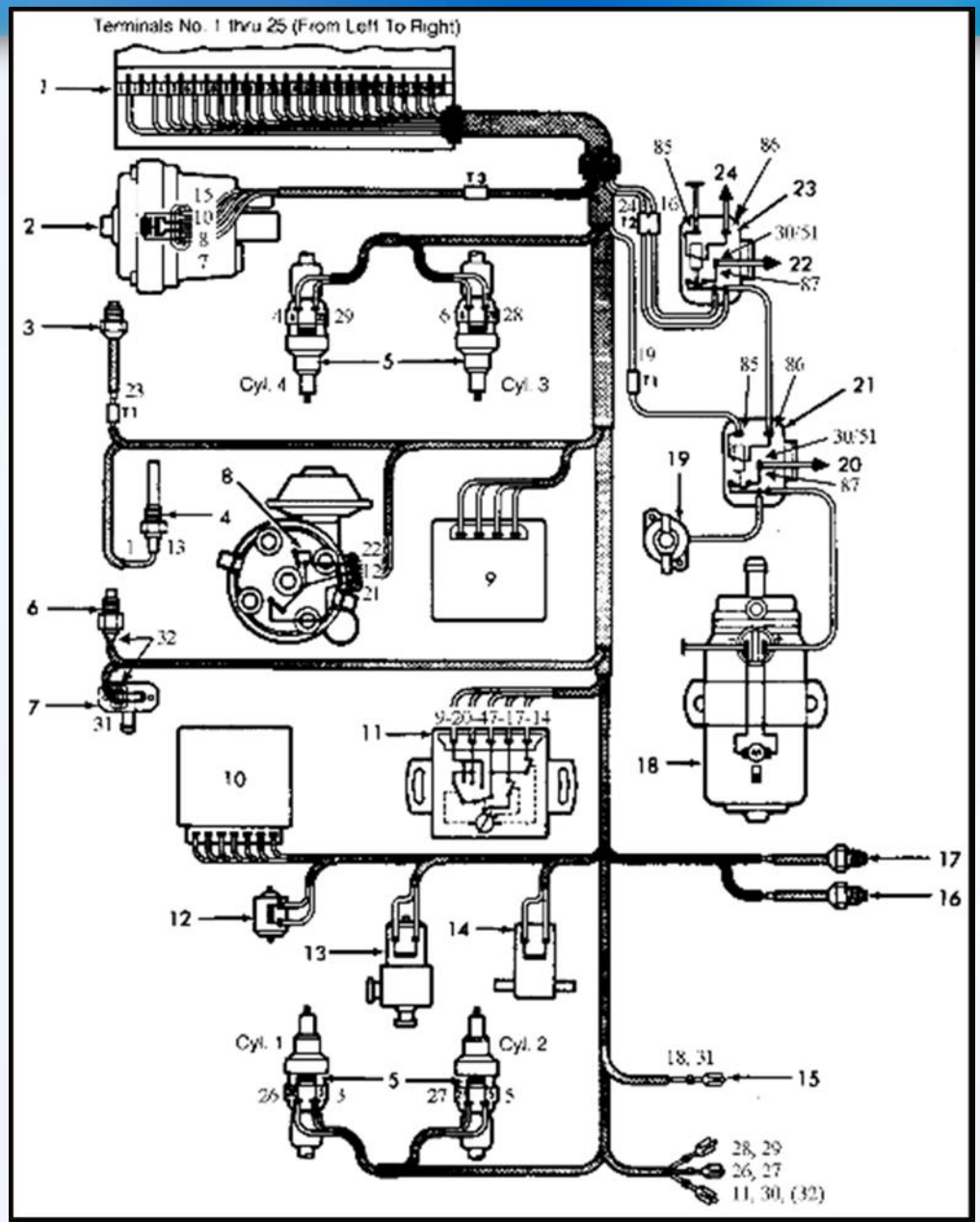


Bosch MPI (D-Jetronic)

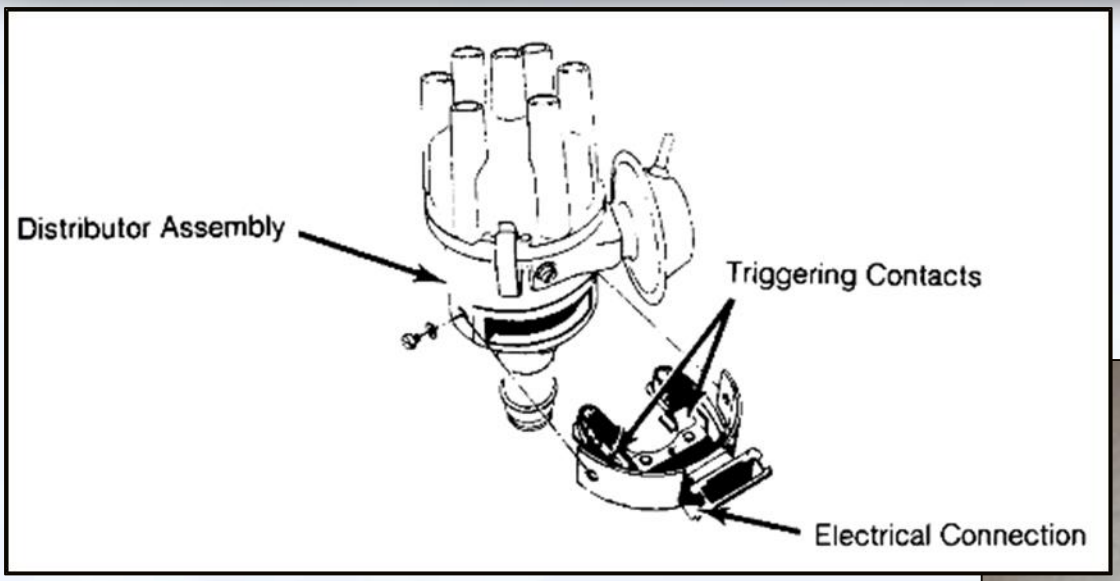
Rube hasn't left the building yet.

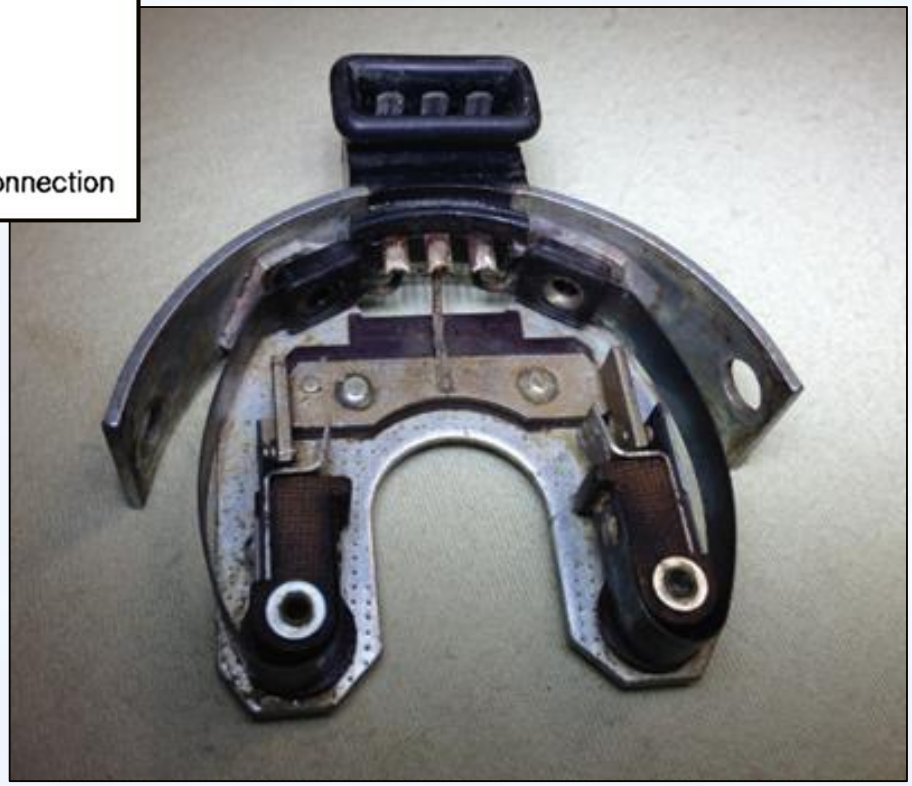
NOTES for Fig. 10: Typical 4-Cyl. Bosch D-Jetronic Fuel Injection Wiring Diagram

1. ECU Connector
2. MPC Sensor
3. Cylinder Head Temp. Sensor
4. Intake Manifold Temp. Sensor
5. Injector
6. Thermotime Switch
7. Cold Start Valve
8. Distributor/Trigger Contacts
9. Engine Speed Relay (1972 models)
10. EGR Switch Unit (Some models)
11. Throttle Valve Switch
12. Vacuum Advance Disconnection 2-Way Valve
13. EGR Valve
14. Air Valve for Auxiliary Air Supply (1972 models)
15. From Starter Terminal No. 50
16. EGR Thermoswitch
17. A/T Oil Pressure Switch (1972 models)
18. Fuel Pump
19. Auxiliary Air Valve (If Equipped)
20. To Fuse Box Terminal No. 30
21. Fuel Pump Relay
22. To Battery
23. Main Relay
24. To Ignition Switch Terminal No. 15 or Ignition Coil Terminal No. 15



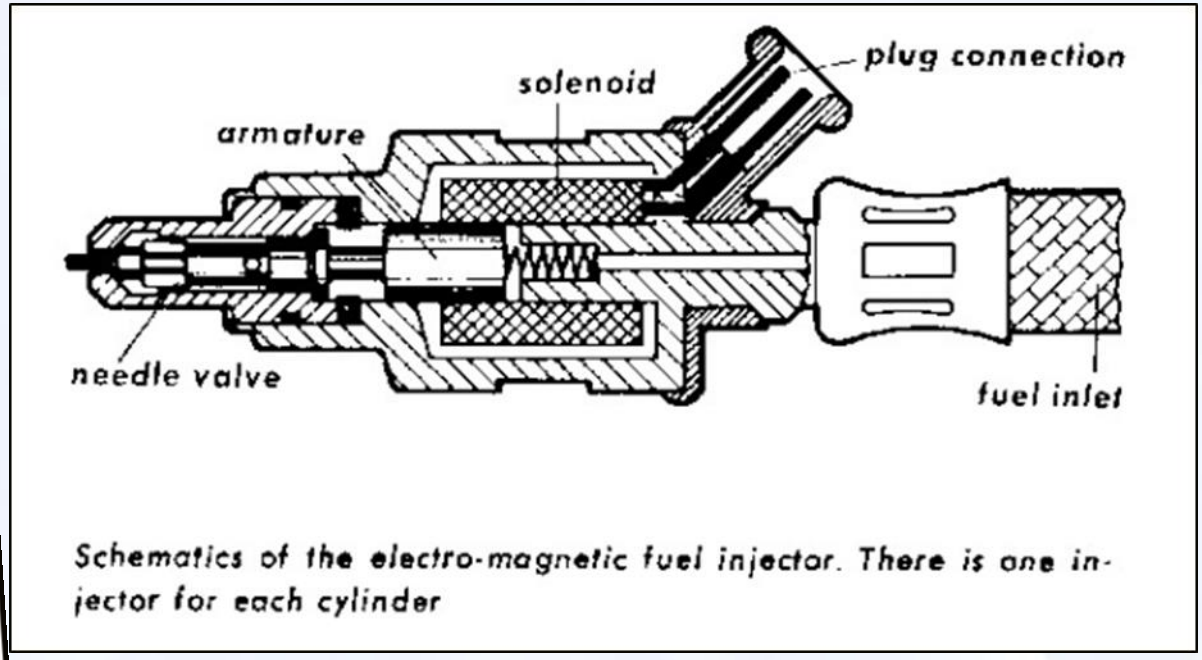
Bosch MPI (D-Jetronic)





The system will determine engine speed AND trigger the injectors by means of mechanical contacts in the distributor in a compartment below the ignition points

Bosch MPI (D-Jetronic)

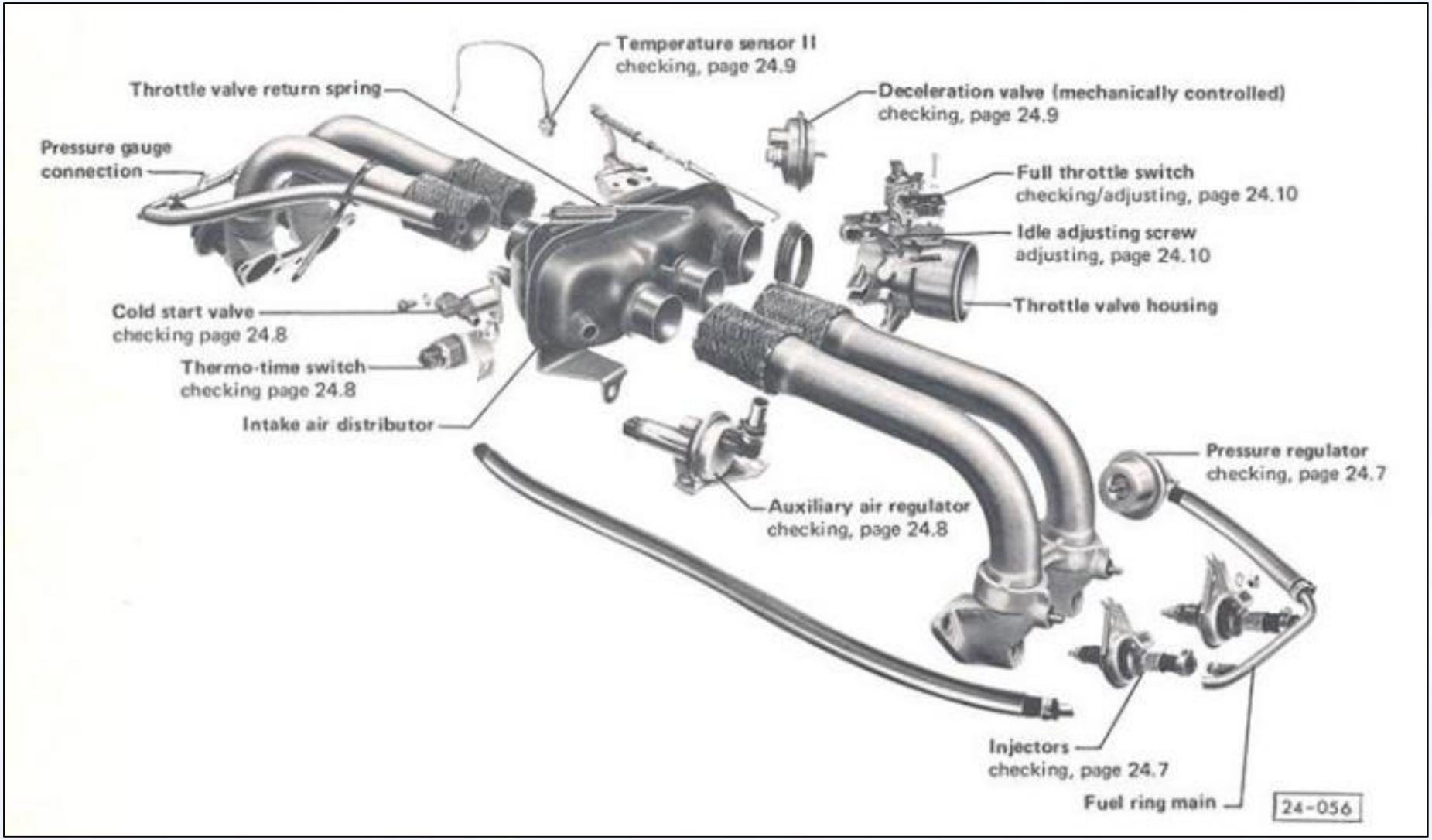


Schematics of the electro-magnetic fuel injector. There is one injector for each cylinder

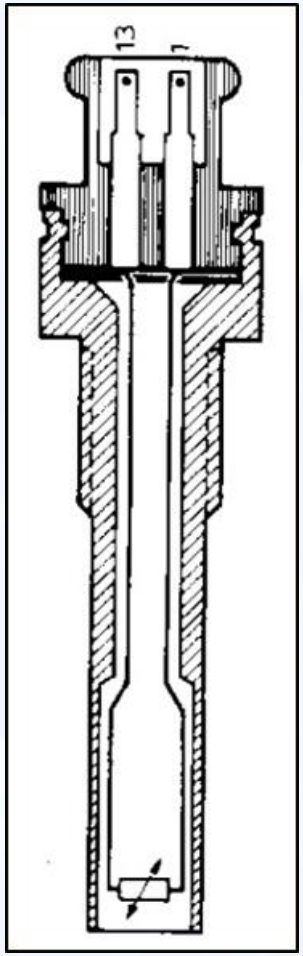
Star of the show is the electro-magnetic fuel injector, a solenoid that opens and shuts fully when activated

Bosch MPI (D-Jetronic)

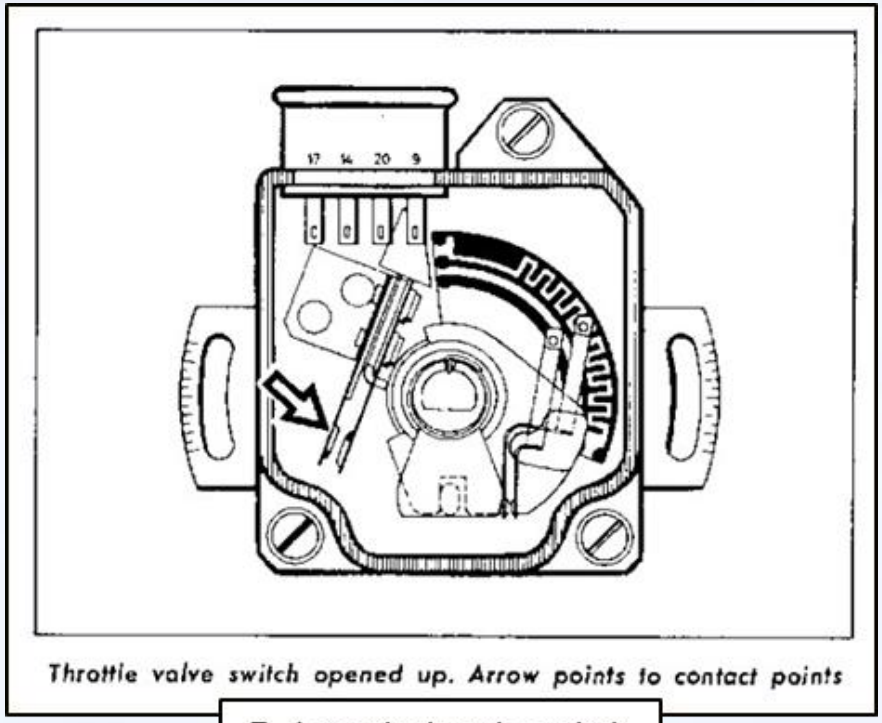
A rather simple layout, introduced on the 914



Bosch MPI (D-Jetronic)



The typical Bosch cylinder head sensor is a variable resistor that lowers its resistance value as the temperature goes up. They're called Negative Temperature Coefficient resistors (NTC).



Throttle valve switch opened up. Arrow points to contact points

D-Jetronic throttle switch

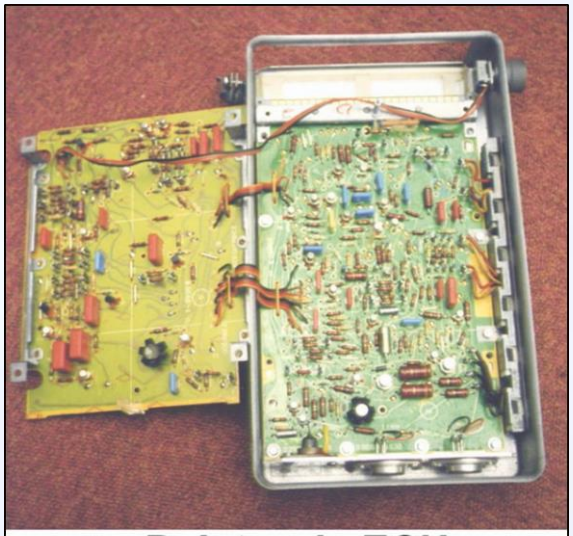
The throttle switch provided idle and part-throttle information to the electronic control unit.

Bosch MPI (D-Jetronic)

The manifold pressure sensor sensed absolute pressure by means of a single vacuum line to the intake manifold

Bosch MPI (D-Jetronic)

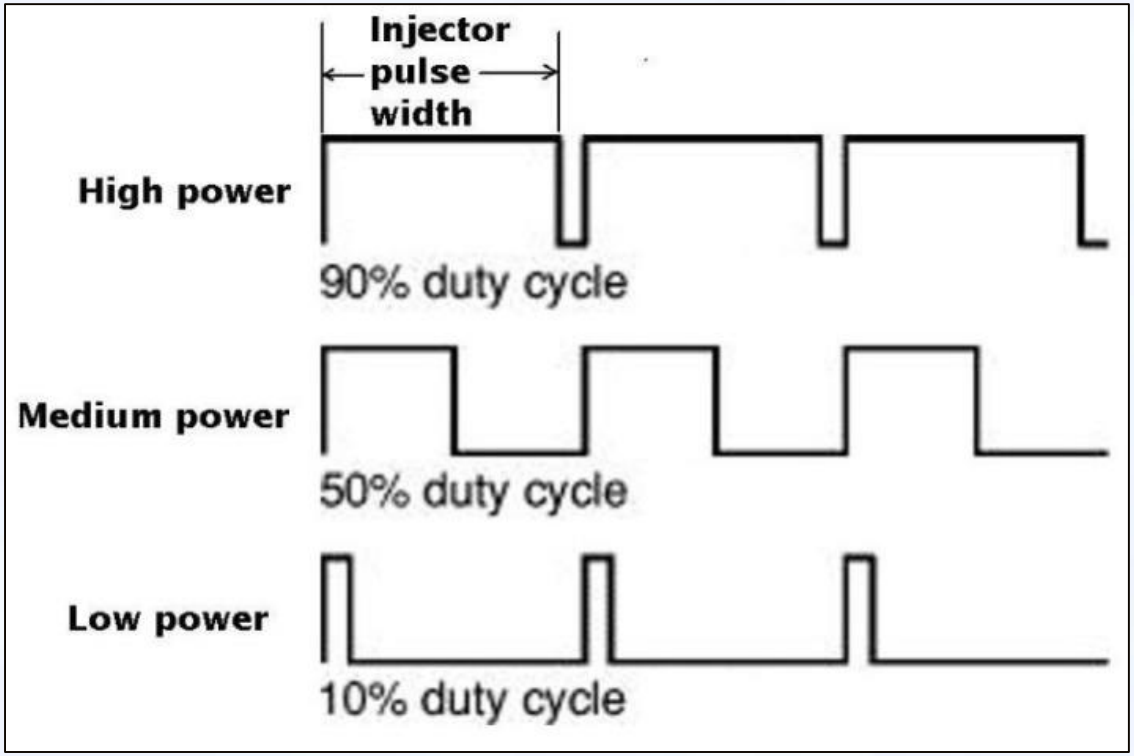
This was Bosch's initial attempt at a modern fuel system controller. They even supplied a shop tester to dealers.



D Jetronic ECU

Time Out!

Let’s focus on a component: Electric Fuel Injectors



The duty cycle is always determined by the electronic control unit

Time Out!

Let's focus on a component: Electric Fuel Injectors

Q: What's the difference between each of these aftermarket applications?
A: The flow rate.

DeatschWerks 18U-01-0650-6 Set of 6 650cc Fuel Injectors (Fits: Porsche GT3)

Authorized Dealer - 60 Day Returns - HUGE Selection

$399.00

List price: ~~$498.75~~

Buy It Now

Free shipping

DeatschWerks 18U-01-0800-6 Set of 6 800cc Fuel Injectors (Fits: Porsche GT3)

Authorized Dealer - 60 Day Returns - HUGE Selection

$399.00

List price: ~~$498.75~~

Buy It Now

Free shipping

DeatschWerks 18U-01-0440-6 Set of 6 440cc Fuel Injectors (Fits: Porsche GT3)

Authorized Dealer - 60 Day Returns - HUGE Selection

$399.00

List price: ~~$498.75~~

Buy It Now

Free shipping

DeatschWerks 18U-01-0550-6 Set of 6 550cc Fuel Injectors (Fits: Porsche GT3)

Authorized Dealer - 60 Day Returns - HUGE Selection

$399.00

List price: ~~$498.75~~

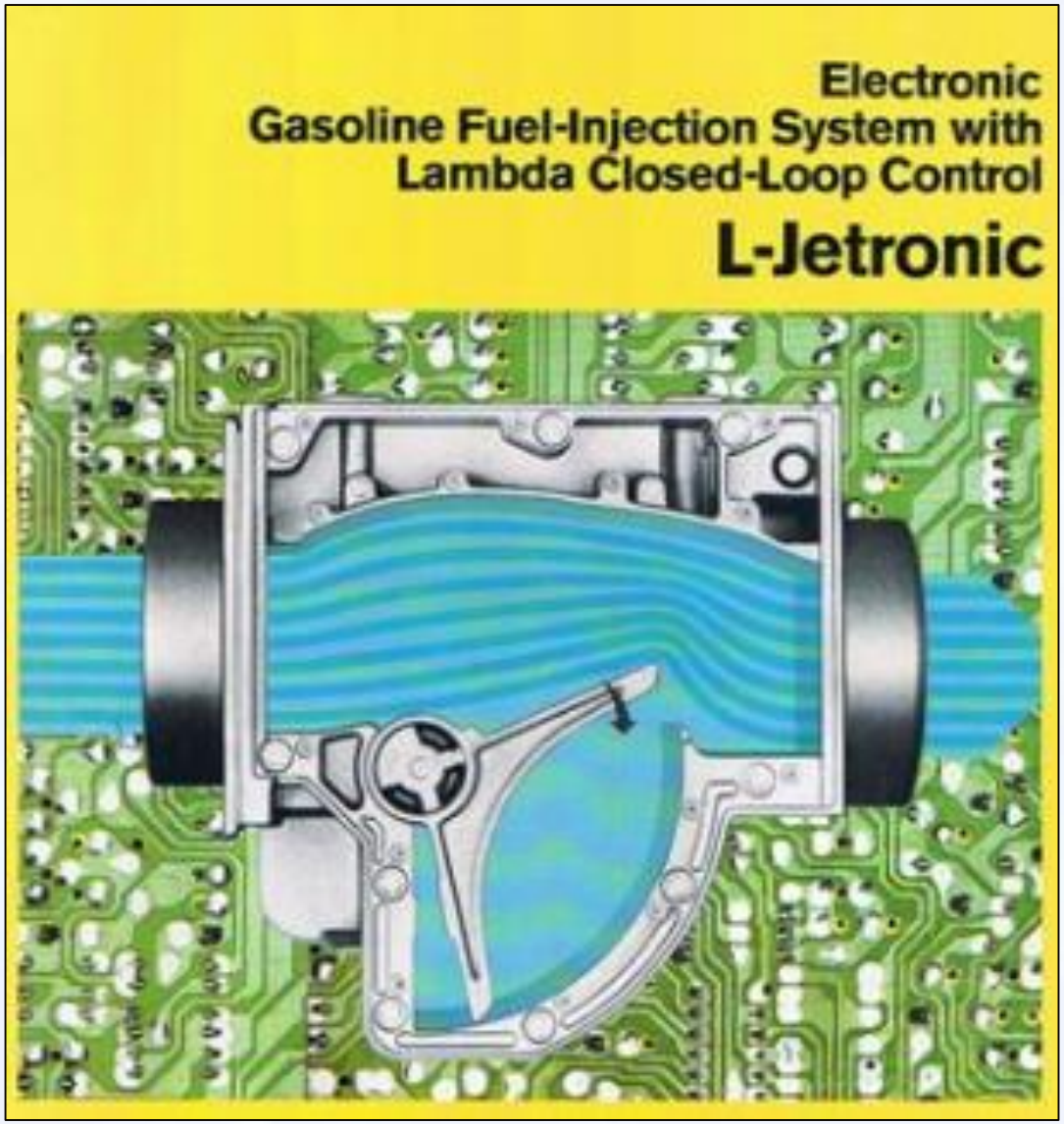
Buy It Now

Free shipping

Air Flow Control
AFC

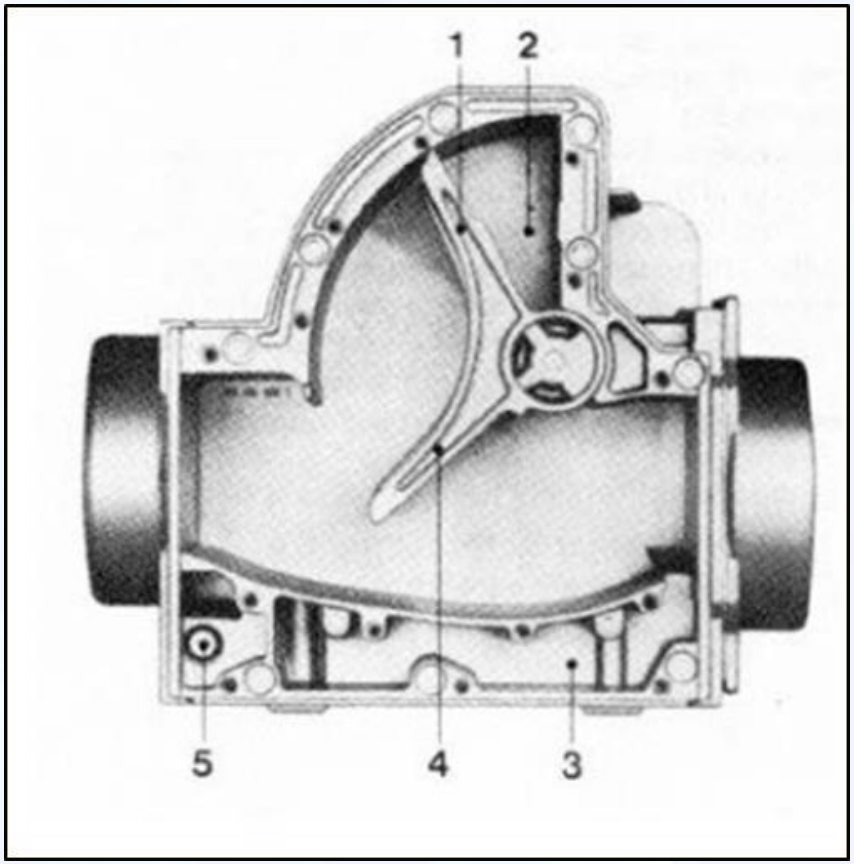
Bosch L-Jetronic

Air Flow Control (L-Jetronic)



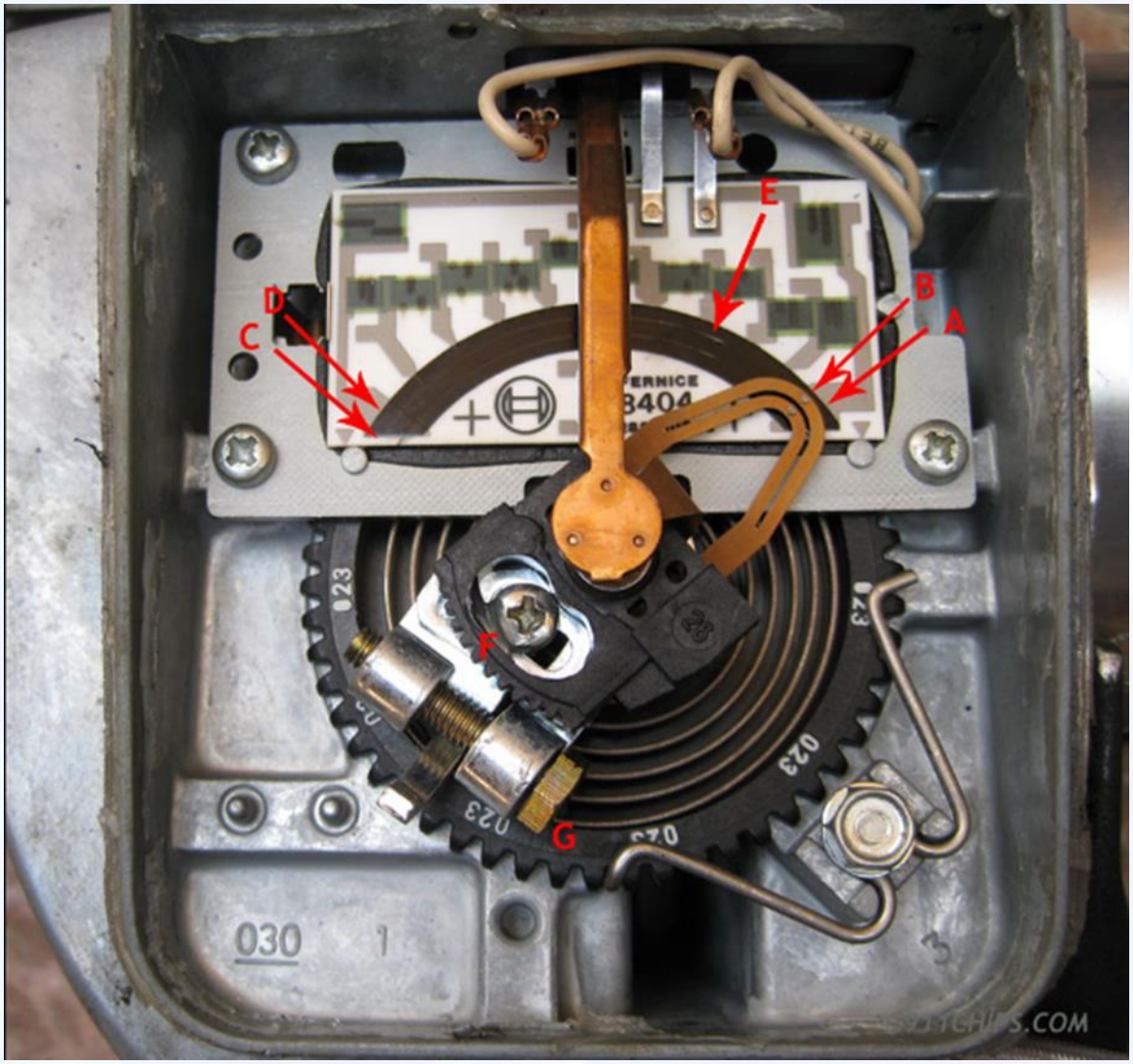
Air Flow Control (L-Jetronic)

The fundamental change from D- to L-Jetronic is the way engine load is measured



L Jetronic Air Flowmeter

Air Flow Control (L-Jetronic)

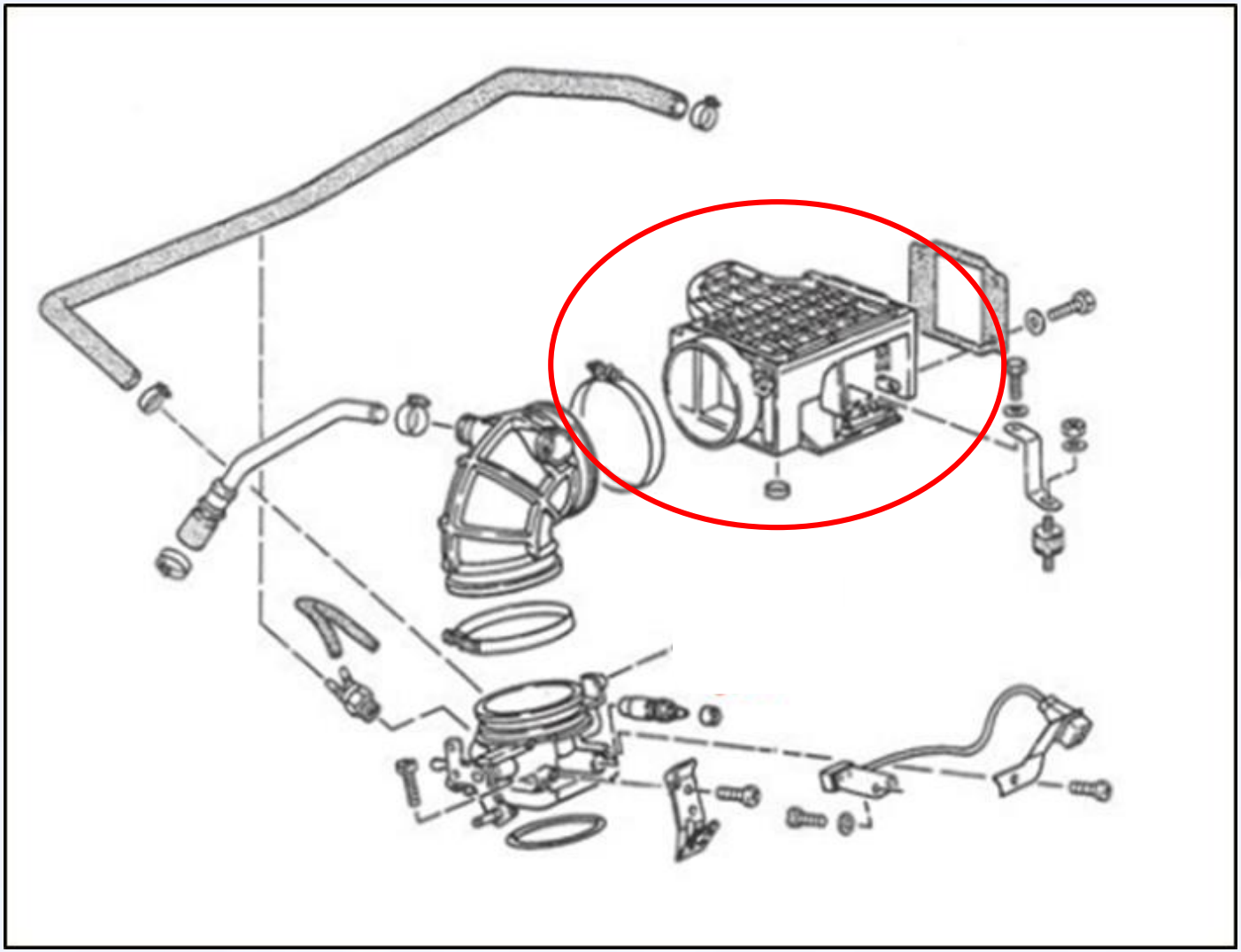


As the air flap moves, a sweeper arm draws across a carbon track with increasing resistance value. This value is understood by the control unit to be the amount of air being pulled into the intake.

A factory-preset steel spring can be seen at the bottom of the assembly.

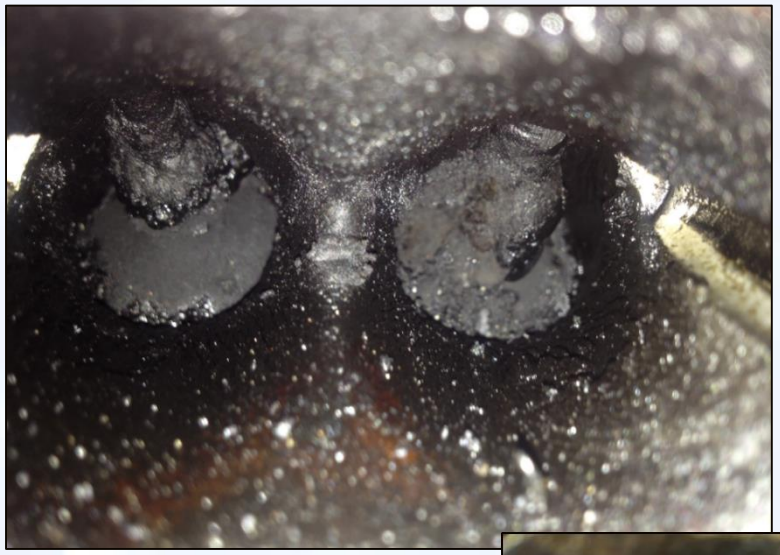
Air Flow Control (L-Jetronic)

We'll find that the L-Jetronic airflow meter will carry over to the DME System



Time Out!

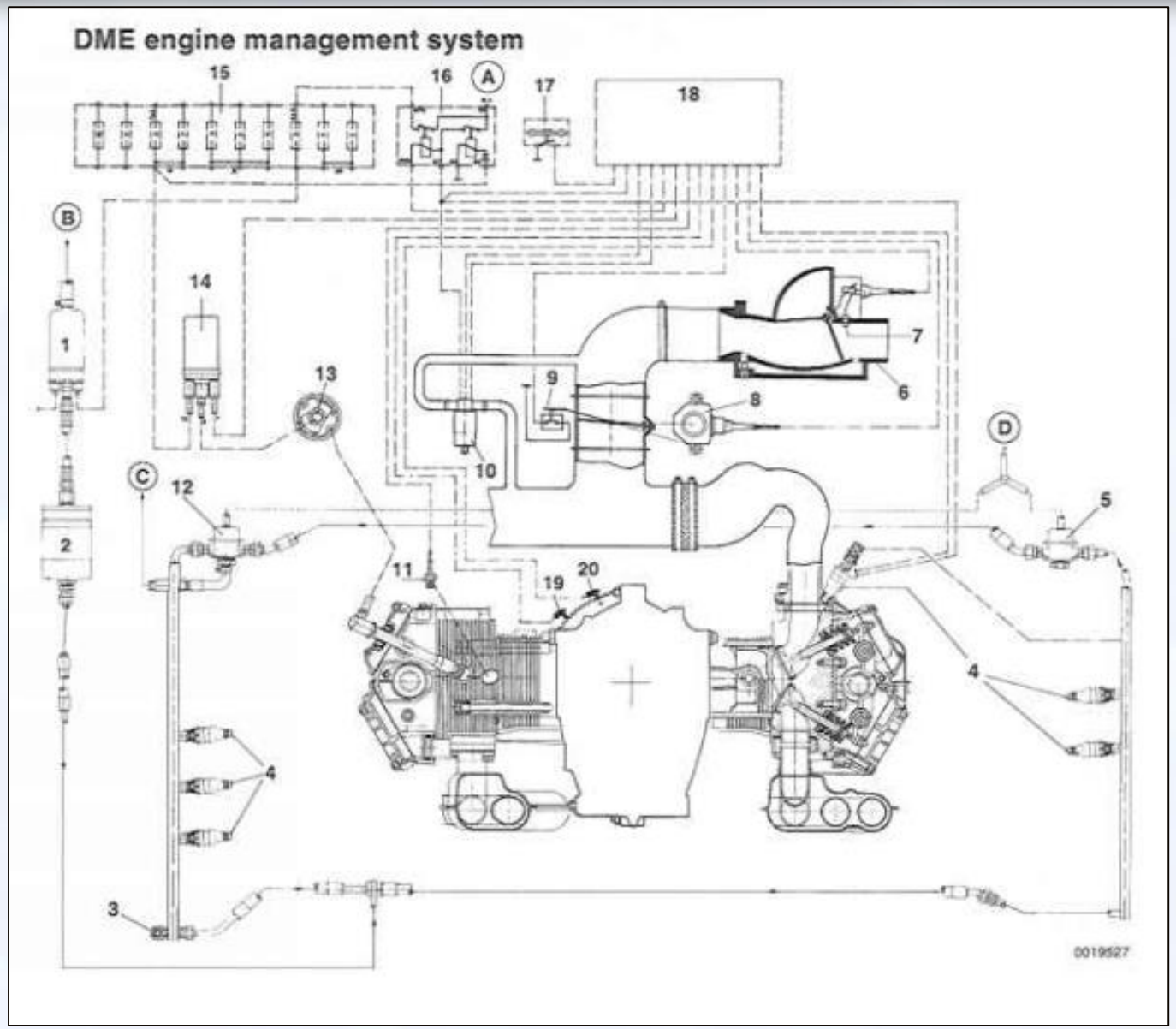
Let’s focus on a situation



Digital Motor Electronic
DME

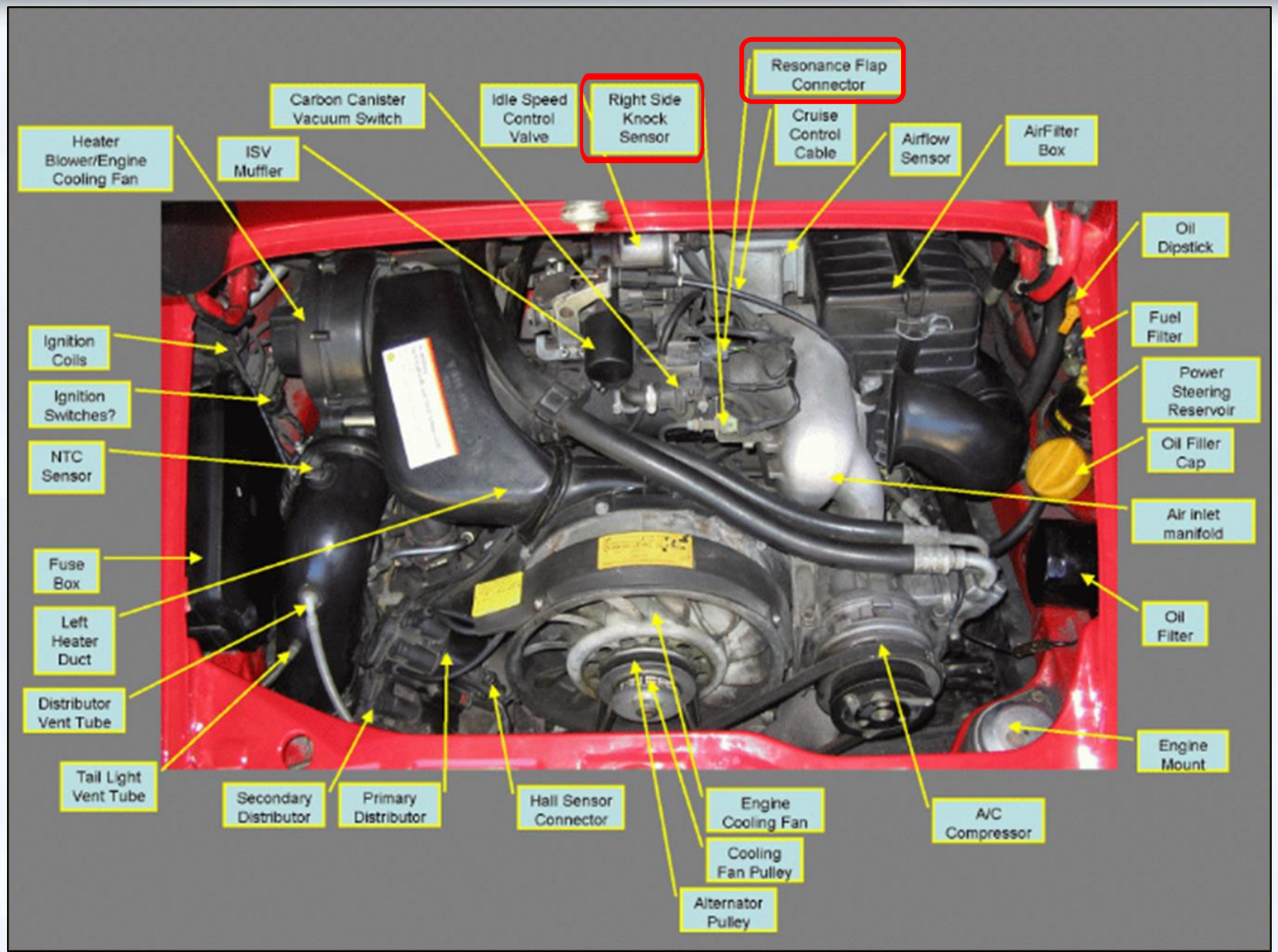
Bosch Motronic

Bosch DME (Motronic)

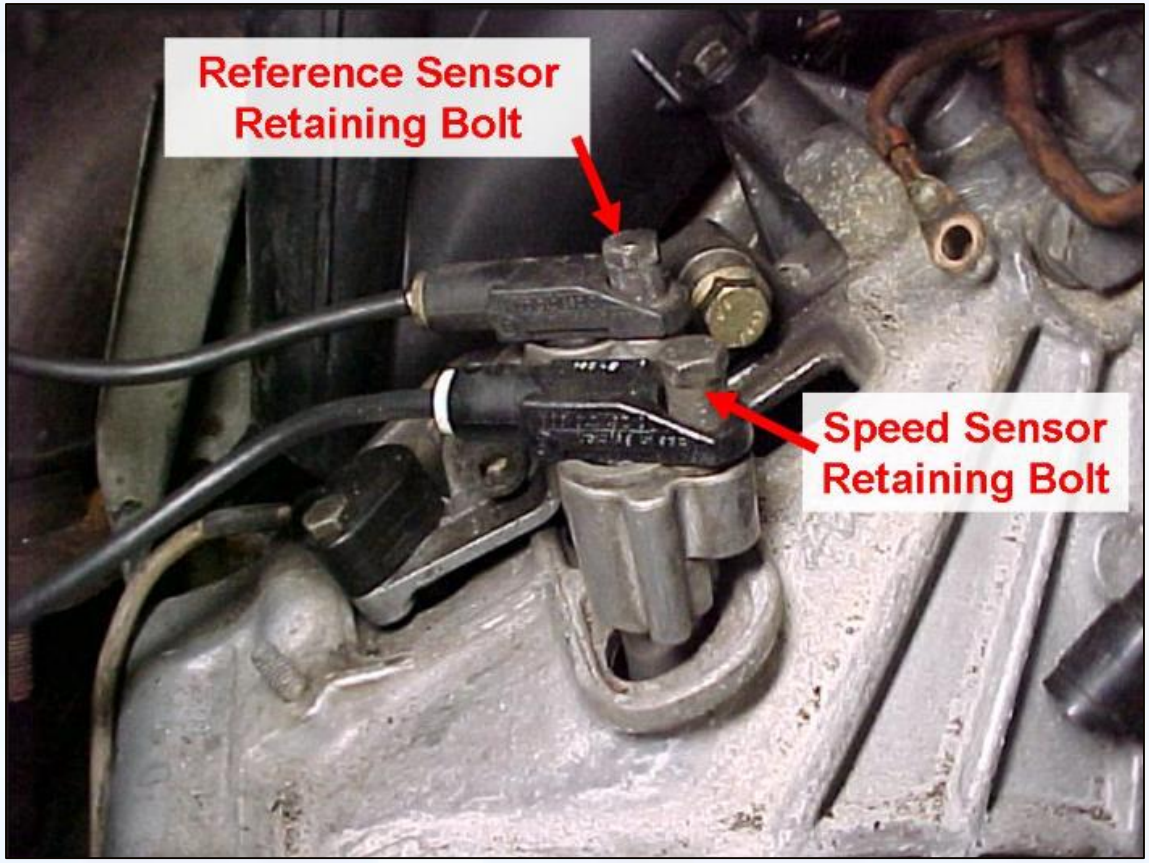


Bosch DME (Motronic)

Bosch DME (Motronic)



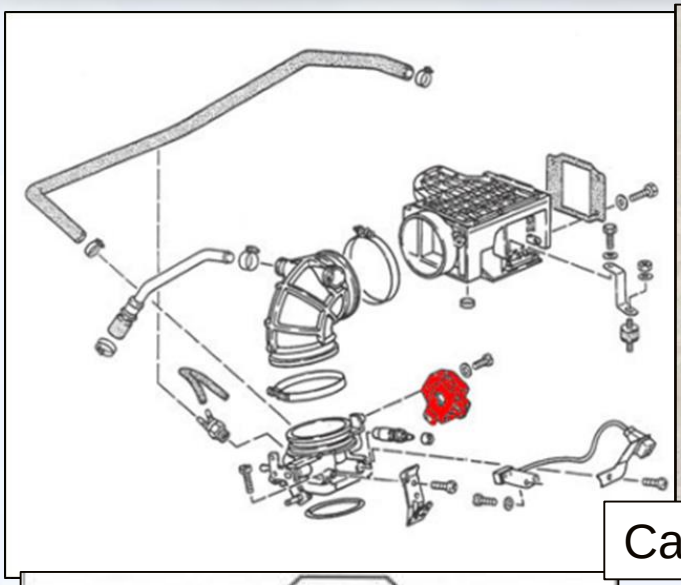
Bosch DME (Motronic)



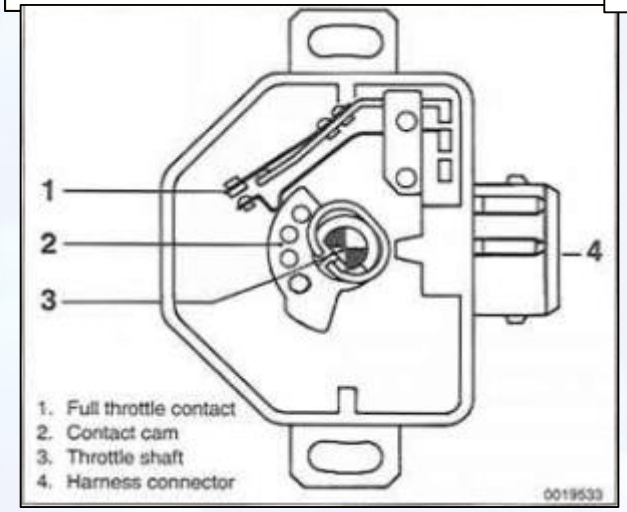
The DME control unit is going to use magnetic sensors to determine engine speed, relationship to Top Dead Center (TDC), and in later versions a cam sensor to determine which cylinder is firing.

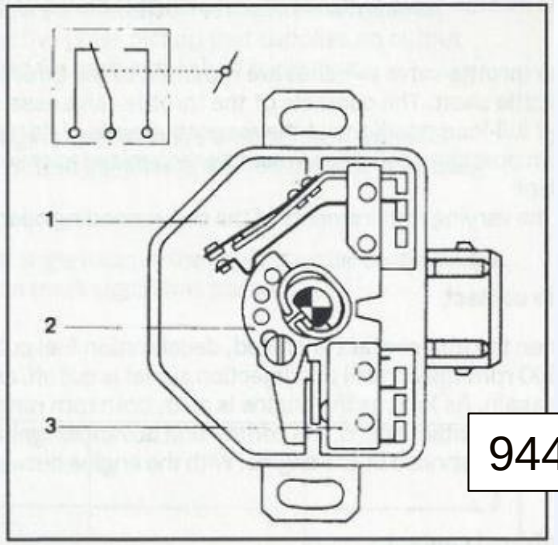
All injectors activate at the same time.

Bosch DME (Motronic)



Carrera





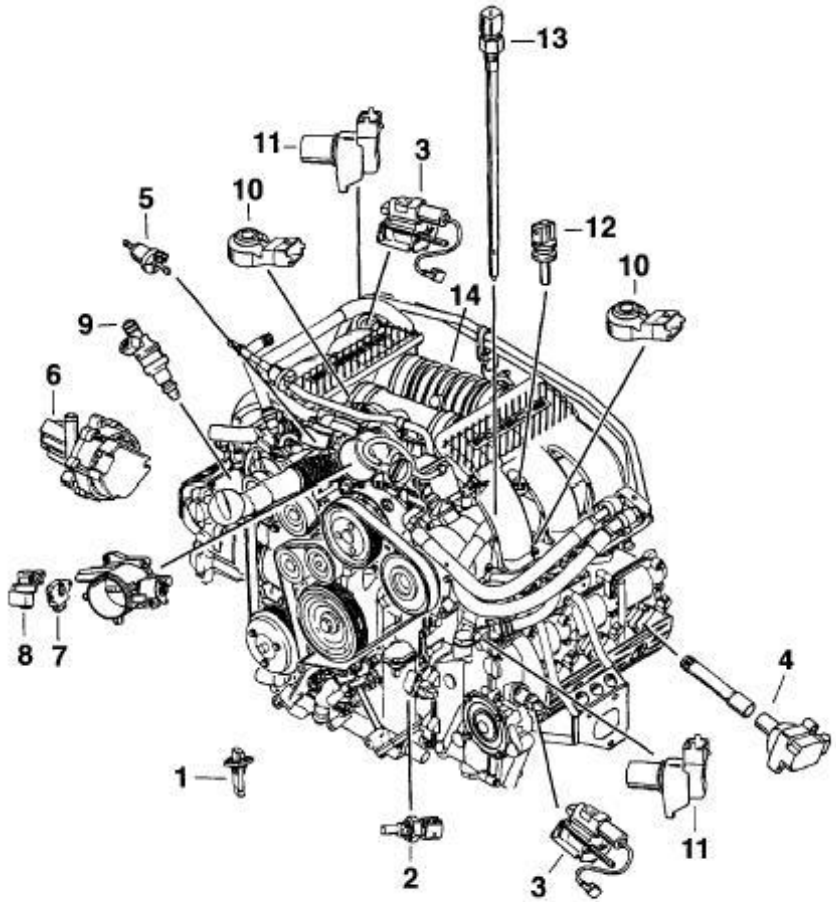
944

As usual, there are model-by-model differences. On the 3.2 liter Carrera there will be a separate idle and full throttle switch. On the 944 the two switches will be integrated into the same housing.

Bosch DME (Motronic)

- Idle speed regulation is also introduced with DME

Bosch DME (Motronic)



1 - Mass air flow sensor
2 - Engine temperature sensor
3 - VarioCam valve
4 - Ignition coil
5 - Tank venting valve
6 - Secondary air pump
7 - Throttle potentiometer
8 - Idle speed air control valve
9 - Injection valve
10 - Knock sensors
11 - Hall-effect sensors
12 - Engine compartment temperature sensor
13 - Oil temperature sensor
14 - Resonance flap

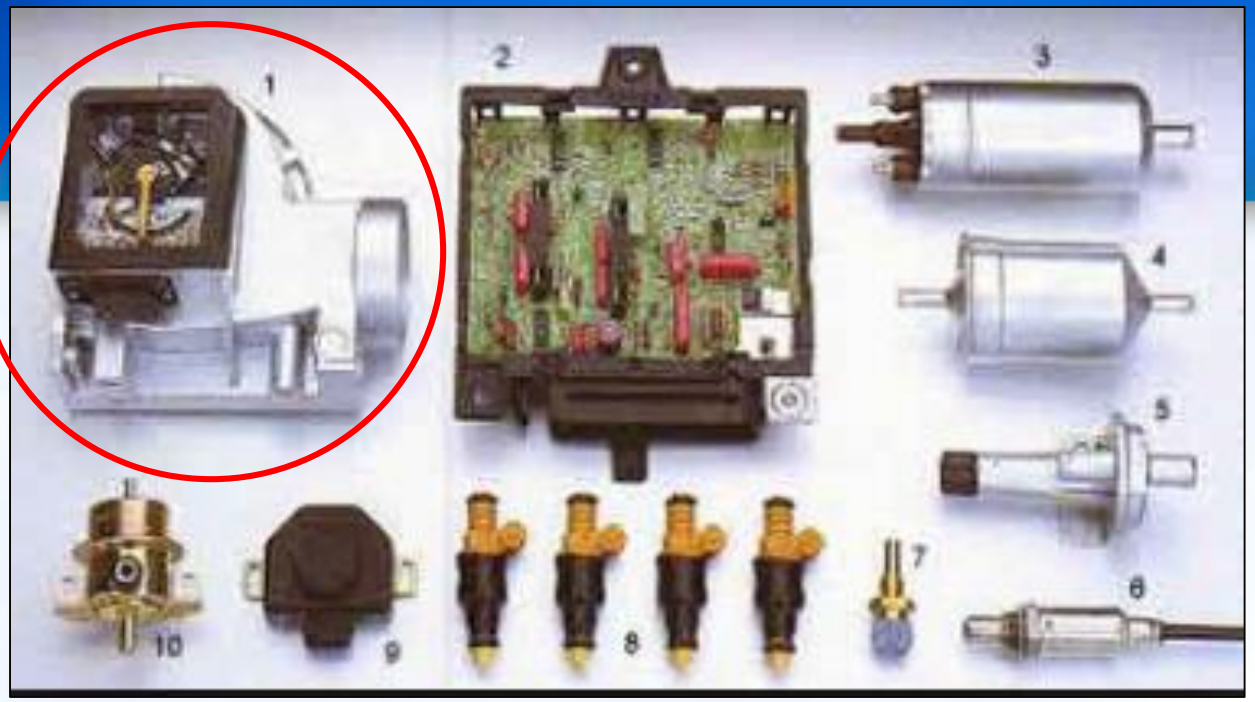
DME continued to evolve by adding electronic control inputs like engine oil temperature in addition to coolant temperature.

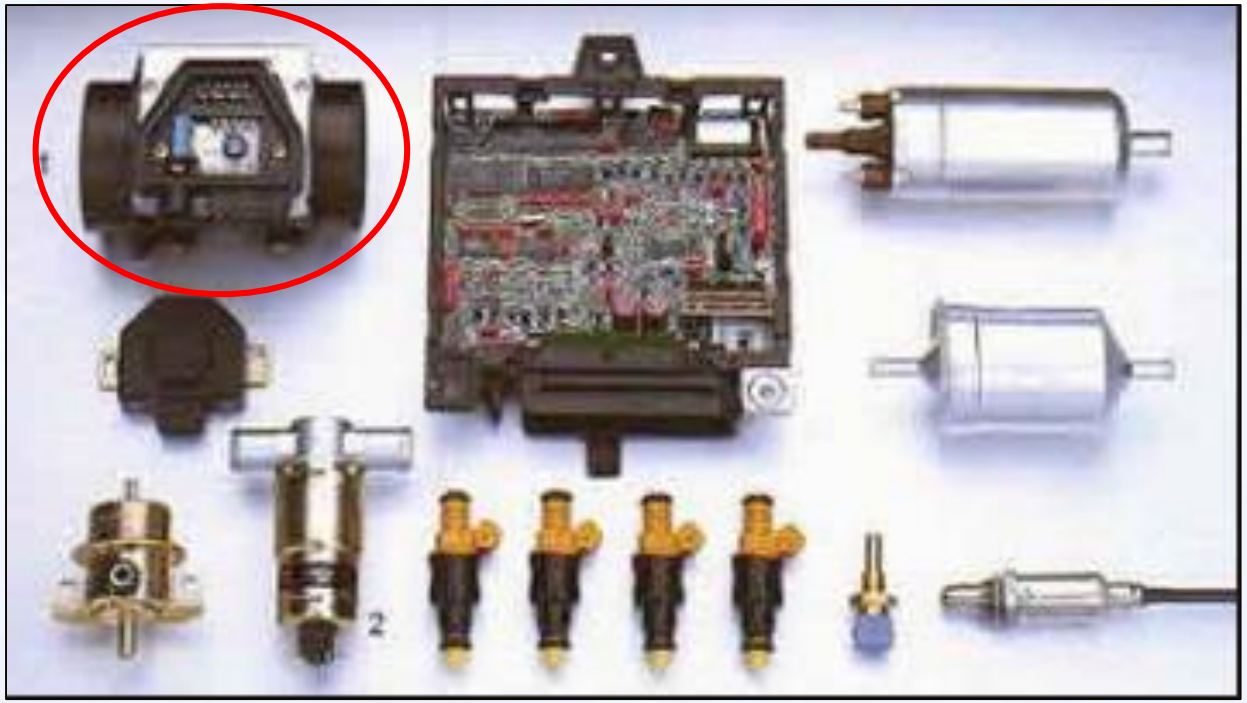
Think About It

Q: What are two motivating factors for fuel injection engineers to make changes to a functional system?
A: Legislation & Cost Reduction.

Hot Wire (Air Mass Sensor)

Bosch LH-Jetronic

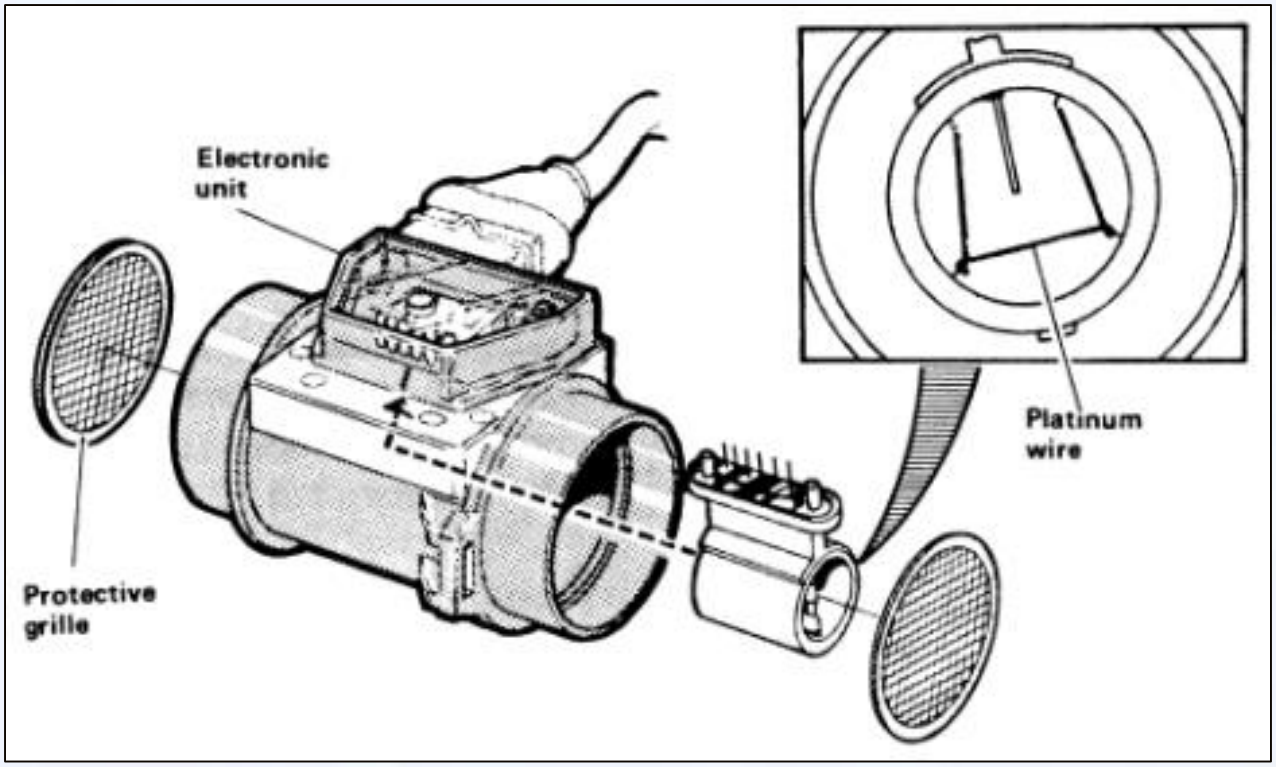




While fundamentally the same as L-Jetronic, LH-Jetronic successfully introduced the idea of measuring air mass instead of air flow.

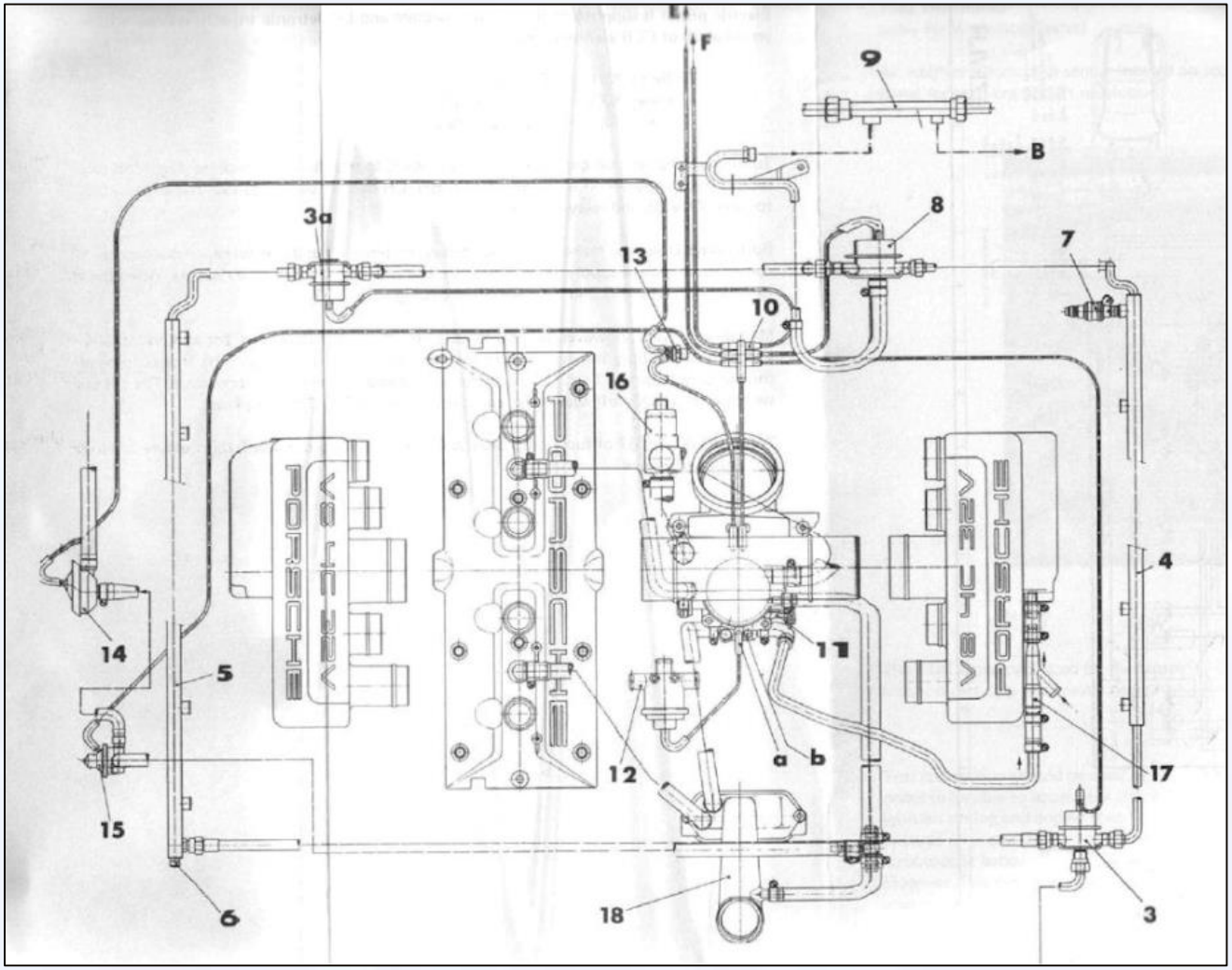
Bosch LH-Jetronic

The air mass sensor uses a voltage usage theory to determine how much air is flowing across a wire that is kept at constant temperature; this compensates for intake air temperature and altitude. The wire must be maintained (cleaned) by burning off impurities picked up from the atmosphere after each drive cycle.



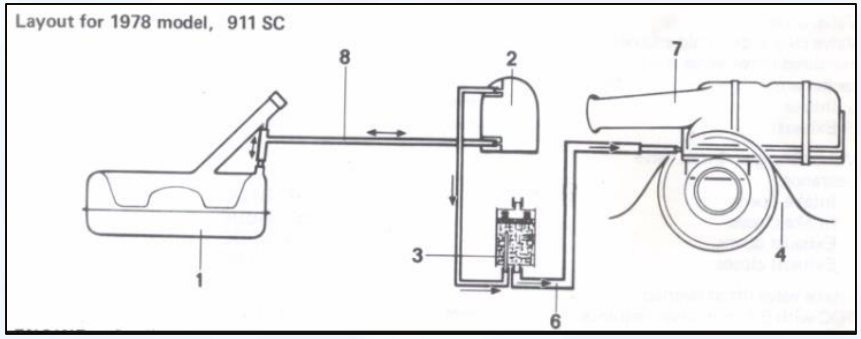
Bosch LH-Jetronic

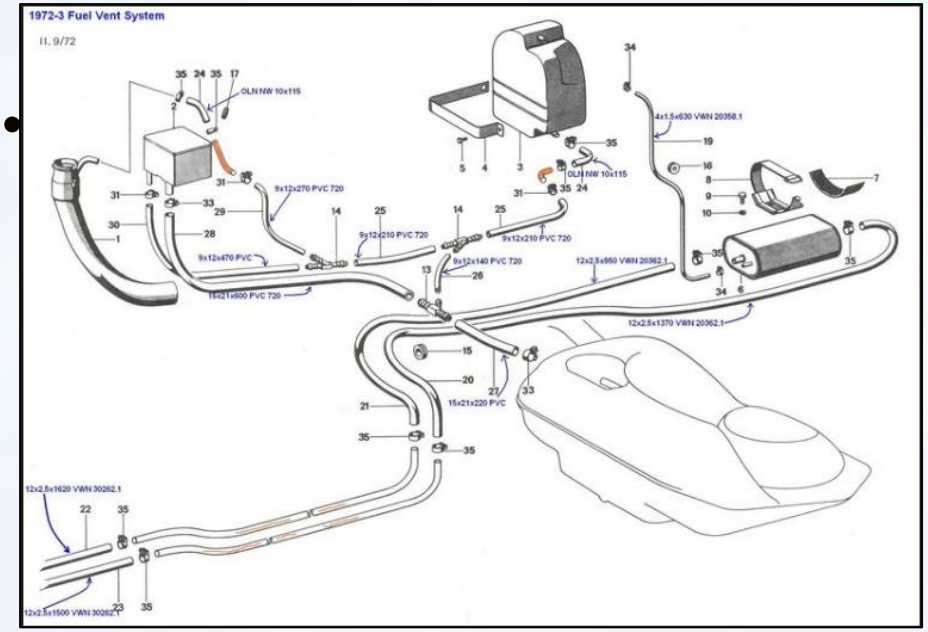
LH technology was introduced on the 928S4 as a standalone fueling system. Ignition was handled by EZF/EZK Ignition Control



Time Out!

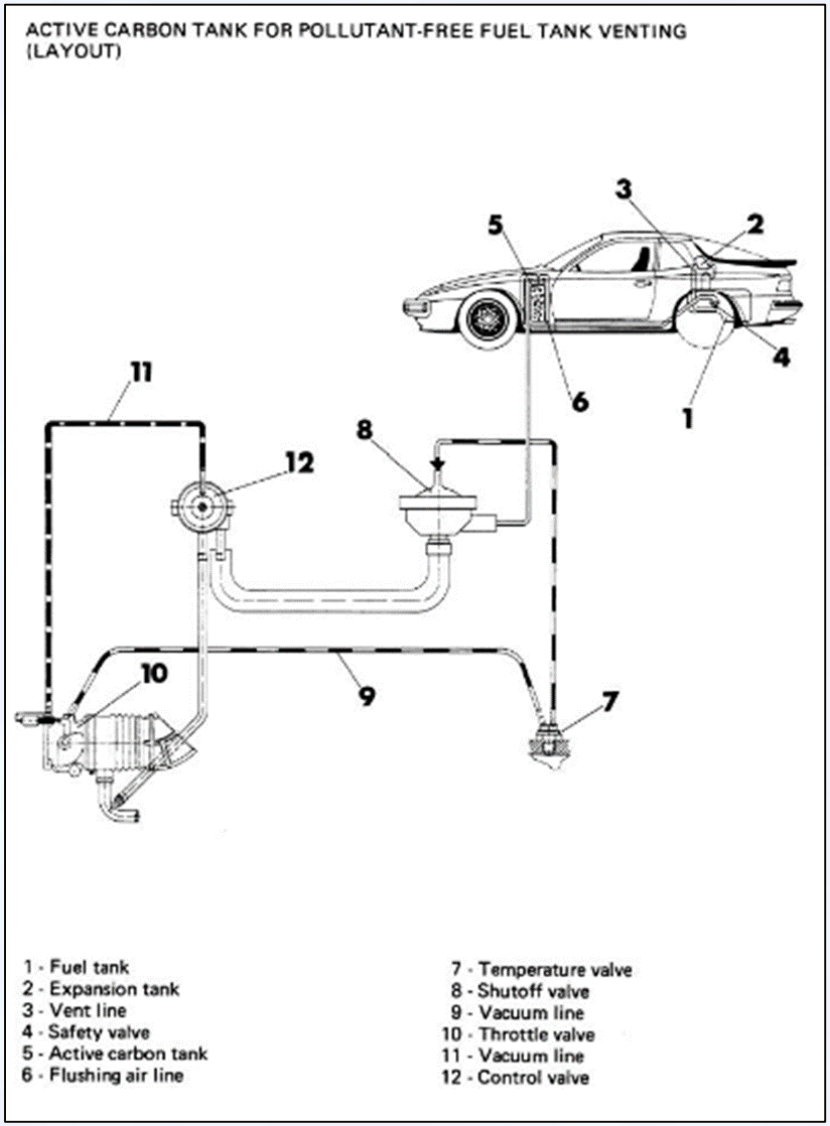
Let's focus on a largely passive, often misunderstood system, fuel vapor recovery

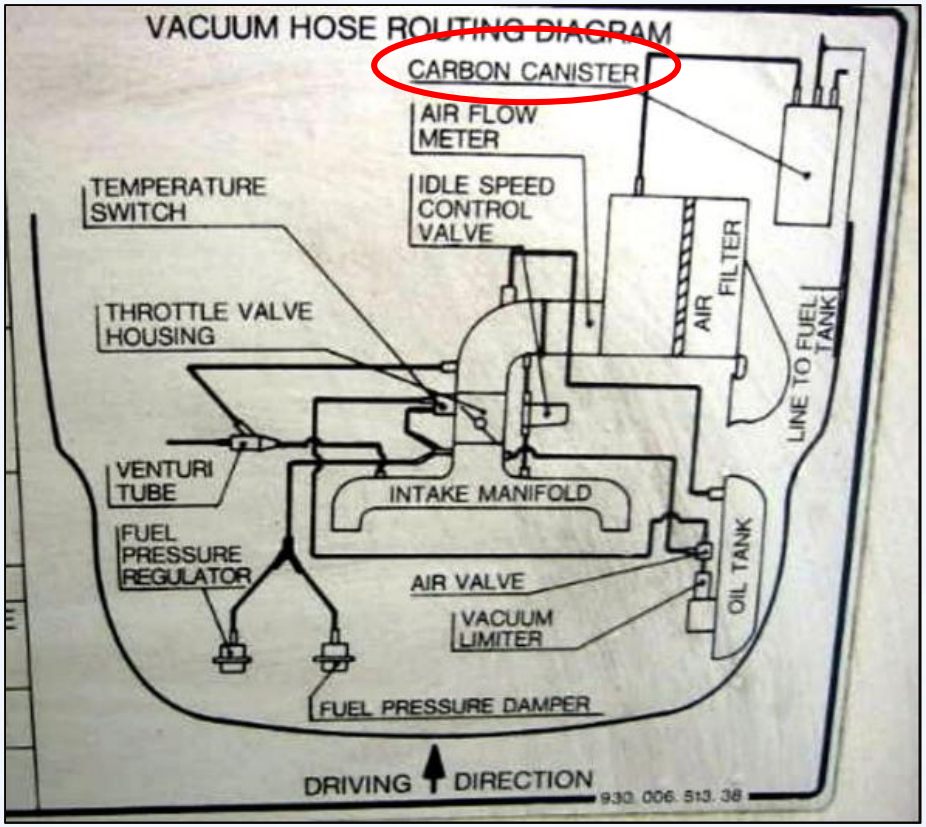




Time Out!

Fuel vapor recovery



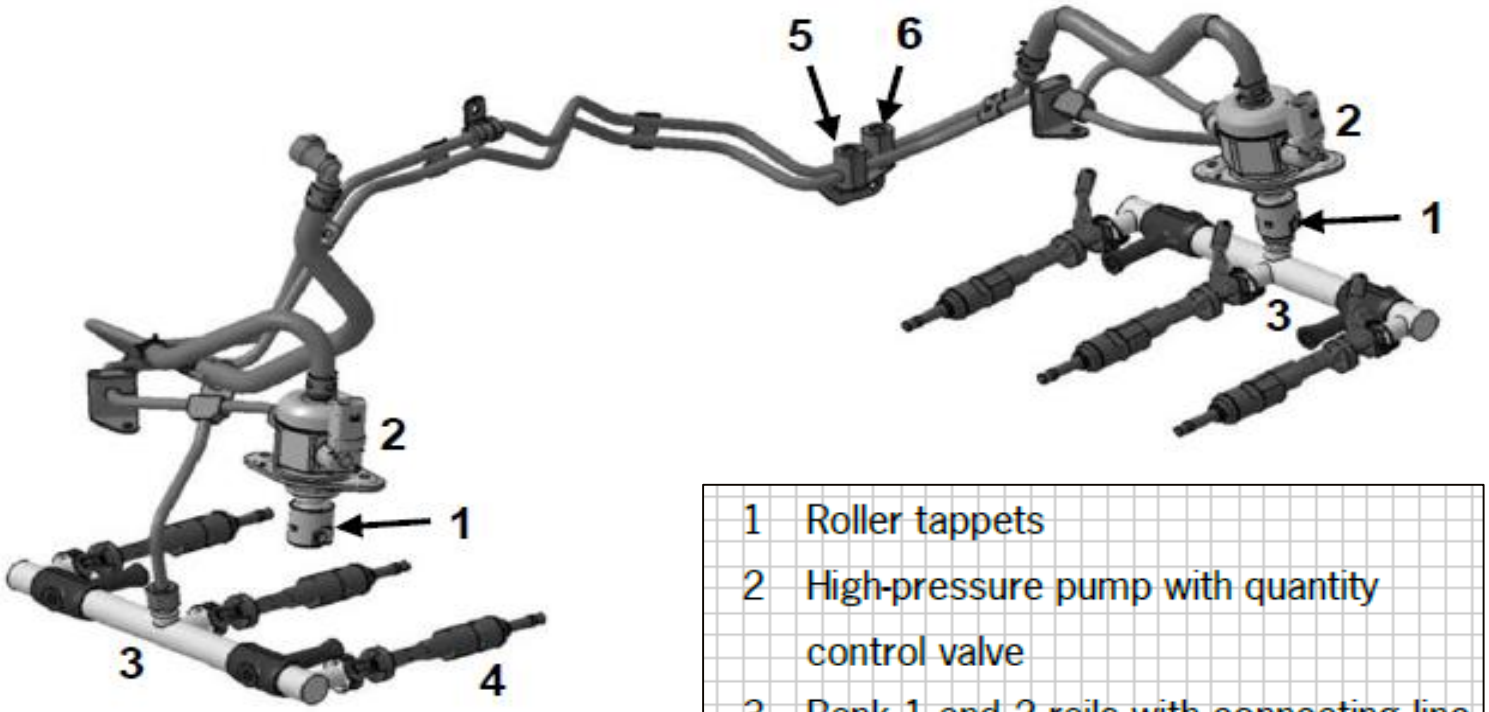


Gasoline Direct Injection GDI

Bosch Motronic

Gasoline Direct Injection (GDI Motronic)

The injectors themselves require higher pressures and a modified injector profile fitted to the center of the combustion chamber



DFI high-pressure system

1	Roller tappets
2	High-pressure pump with quantity control valve
3	Bank 1 and 2 rails with connecting line
4	7-hole injectors
5	High-pressure sensor
6	Low-pressure sensor

Gasoline Direct Injection (GDI Motronic)

911 Carrera
Model Year 2017

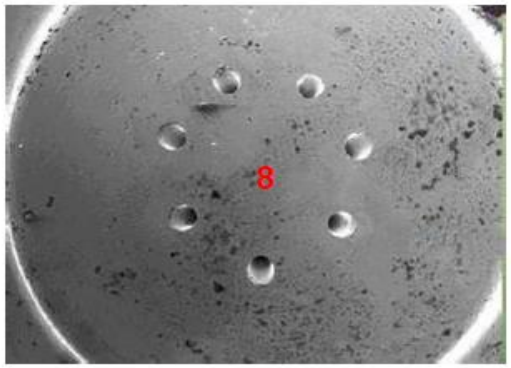
DME engine electronics 2

1 Electrical connection
2 O-ring (high-pressure side)
3 Holding-down device
4 Recess seal
5 Spacer ring
6 Circlip
7 Teflon sealing ring (to combustion chamber)
8 7-hole injector

Injectors

The central position of the 7-hole injector in the cylinder head promotes a homogeneous, symmetrical fuel distribution in the cylinder.

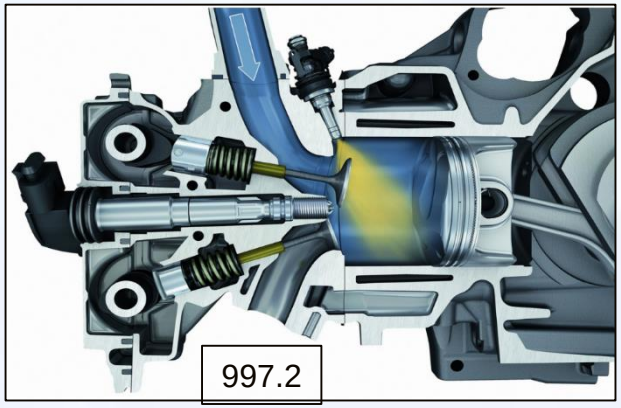
Voltage boosters with flexible drivers are installed in the DME control unit for activation of the injectors.



7-hole injector 2_07_16

Injector position

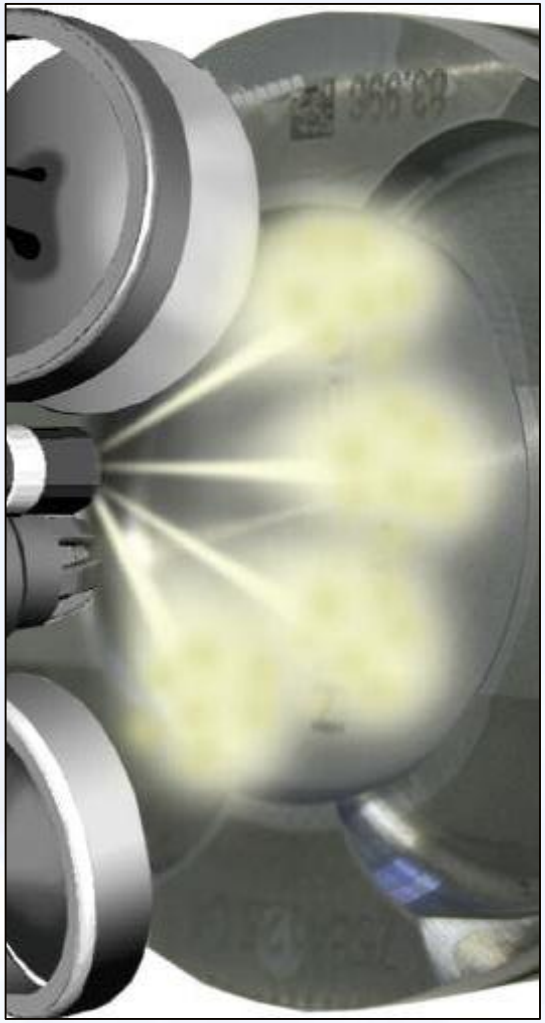
8 7-hole injector
9 Central injector position



997.2

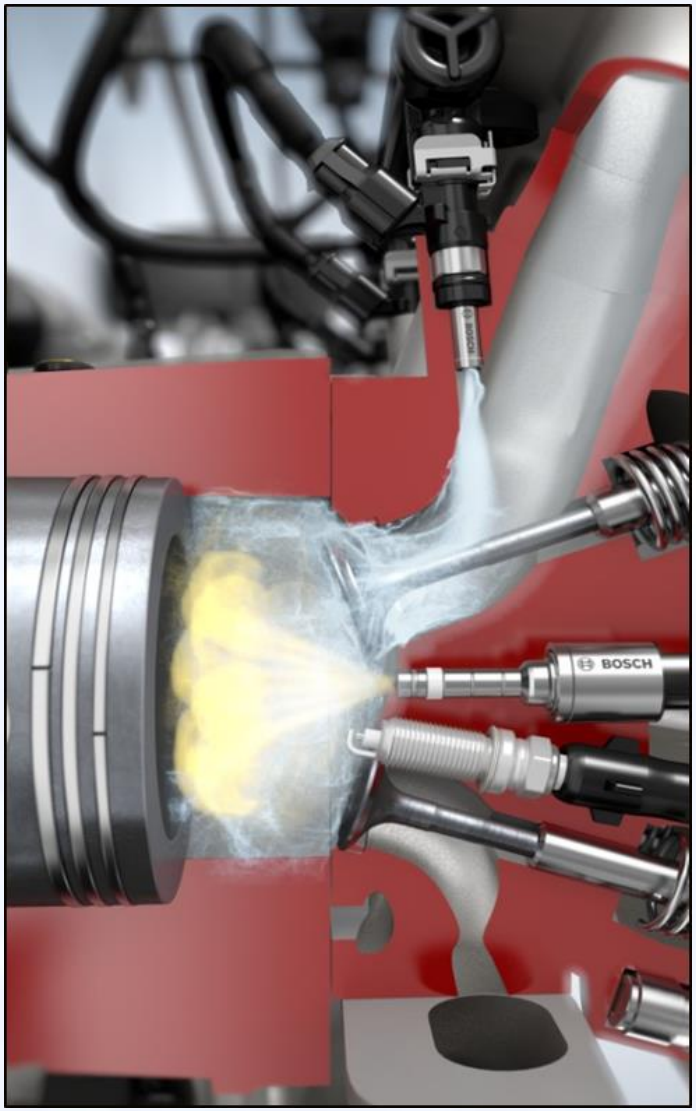
Gasoline Direct Injection (GDI Motronic)

Injector orientation and spray pattern can be optimized for best atomization, resulting in both power and efficiency



So what could possibly be next?

Now in development: water injection



So, what should I take away from all this?

Two Final Takeaways

1. Fuel Injection is fundamentally simple.

Fuel injection volume = Fuel pressure x Fuel timing x Fuel Injector Size

2. Don't believe everything you read.

17 Pictures Of Bill Clinton Playing With Balloons That You Need To See Before You Die

It's important.

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Thanks for your attention!

Your presenter: Bill Burris

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