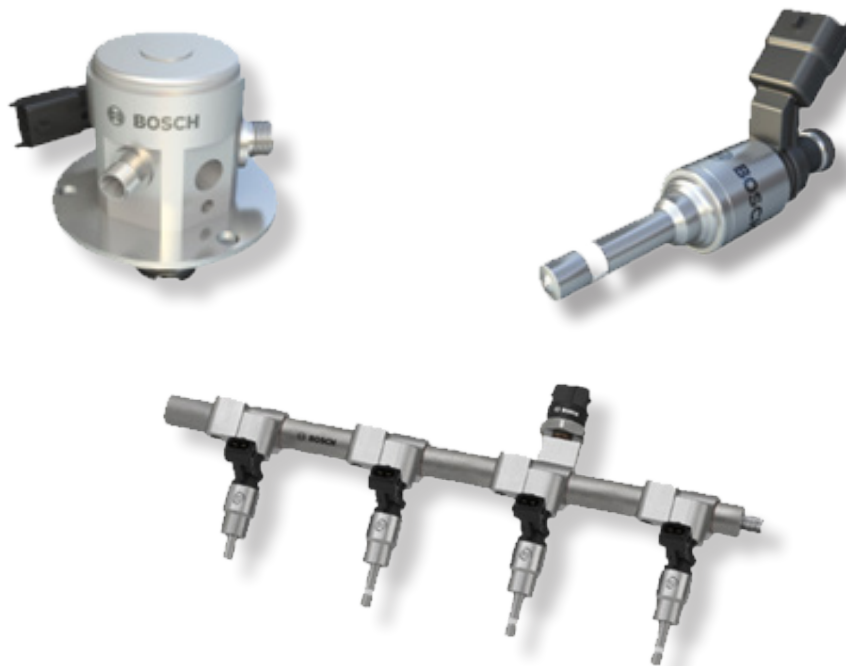


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A ConsuLab presentation

GASOLINE DIRECT INJECTION



Teaching GDI to your students

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GASOLINE DIRECT INJECTION

INTRODUCTION:

Gasoline Direct Injection (GDI) is certainly not new. The first known application of this technology was introduced in 1925 in a Hesselman engine for airplanes. Cars starting using it in the 50's with the Mercedes Benz Gullwing (1953) having this technology. It certainly wasn't the same as the technology we use today, but had the foundations of this operational platform.

In today's market, the high majority of the current OEM manufacturers have at least one and in most cases, many GDI equipped engines in their product line. Most experts agree that GDI will soon replace the conventional port fuel injection systems that we have been familiar with for years.

As new technologies come and go, based on many reasons, it looks like GDI is here to stay. It certainly isn't a perfect technology and there is work presently going on to correct some issues, but the advantages seem to far outweigh any disadvantages and the benefits of having this technology are impressive.

HISTORY:

- **CARBURETORS** _____

- **FEEDBACK CARBURETORS** _____

How did feedback carburetors meter fuel?

INPUTS: TP – ECT – O2 – MAP/BARO – KNOCK SENSOR

OUTPUTS: MIXTURE CONTROL SOLENOID (DUTY CYCLE)(10 CYCLES PER SECOND) "DWELL"
SOME EMISSION DEVICES (AIR PUMP, DIVERTER VALVE, EGR)
THROTTLE SOLENOID (A/C) & TCC LOCK UP

TYPICAL FUEL PRESSURE: 3-5 psi

So, what's wrong with carburetors??

SMOG – EMISSIONS – LACK OF ACCURATE FUEL CONTROL

GASOLINE DIRECT INJECTION

- **THROTTLE BODY INJECTION (TBI)** _____

How did TBI systems meter fuel?

INPUT SENSORS: TP – ECT – O₂ – MAP – BARO – IAT – KNOCK – RPM (DISTRIBUTOR REFERENCE)

OUTPUT DEVICES: INJECTOR PULSE WIDTH (ms) FUEL PUMP RELAY (2 sec PRIME PULSE), EMISSION

CONTROL DEVICES: EGR, DIVERter, TCC LOCKUP, TIMING SPARK ADVANCE/RETARD

TYPICAL FUEL PRESSURE: 12-15 psi (SOME EXCEPTIONS NOTED)

- **CENTRAL PORT INJECTION (CPI)** _____

How did central point systems meter fuel?

INPUT SENSORS: TP – ECT – O₂ – MAP – BARO – IAT – KNOCK – RPM (DISTRIBUTOR REFERENCE)

OUTPUT DEVICES: INJECTOR PULSE WIDTH (ms), FUEL PUMP RELAY (2 sec PRIME PULSE), EMISSION

CONTROL DEVICES: EGR, DIVERter, TCC LOCKUP, TIMING SPARK ADVANCE/RETARD

TYPICAL FUEL PRESSURE: 58-62 psi (VERY SENSITIVE TO SLIGHT LOW PRESSURES)

- **PORT FUEL INJECTION (PFI)** _____

How did port fuel systems meter fuel?

INPUT SENSORS: TP – ECT – O₂ – MAP – BARO – IAT – KNOCK – RPM (DISTRIBUTOR REFERENCE) – MAF

OUTPUT DEVICES: INJECTOR PULSE WIDTH (ms), FUEL PUMP RELAY, TIMING, TCC, EMISSION

TYPICAL FUEL PRESSURE: 40-60 psi

GASOLINE DIRECT INJECTION

- **DIRECT FUEL INJECTION (DFI or GDI)** _____

- **A bit of fuel injection history...**

An early use of indirect gasoline injection dates back to 1902, when French aviation engineer Leon Levasseur pioneered it on his Antoinette 8V aircraft powerplant.

Another early use of gasoline direct injection (i.e. injection of gasoline, also known as petrol) was on the Hesselman engine invented by Swedish engineer Jonas Hesselman in 1925. Hesselman engines use the ultra lean burn principle; fuel is injected toward the end of the compression stroke, then ignited with a spark plug.

Direct fuel injection was used in notable World War II airplane engines such as the Junkers Jumo 210, the Daimler-Benz DB 601, the BMW 801, the Shvetsov ASh-82FN (M-82FN). German direct injection petrol engines used injection systems developed by Bosch from their diesel injection systems.

In the 1940s, hot rodder Stuart Hilborn offered mechanical injection for racers, salt cars, and midgets. 911 production range and until 1975 on the Carrera 3.0 in Europe. Porsche continued using this system on its racing cars into the late seventies and early eighties.

The first commercial electronic fuel injection (EFI) system was the ELECTROJECTOR developed by Bendix Corporation in 1957. Chrysler offered Electrojector on the 1958 Chrysler 300D, DeSoto Adventurer, Dodge D-500 and Plymouth Fury, arguably the first series-production cars equipped with an EFI system. It was jointly engineered by Chrysler and Bendix.

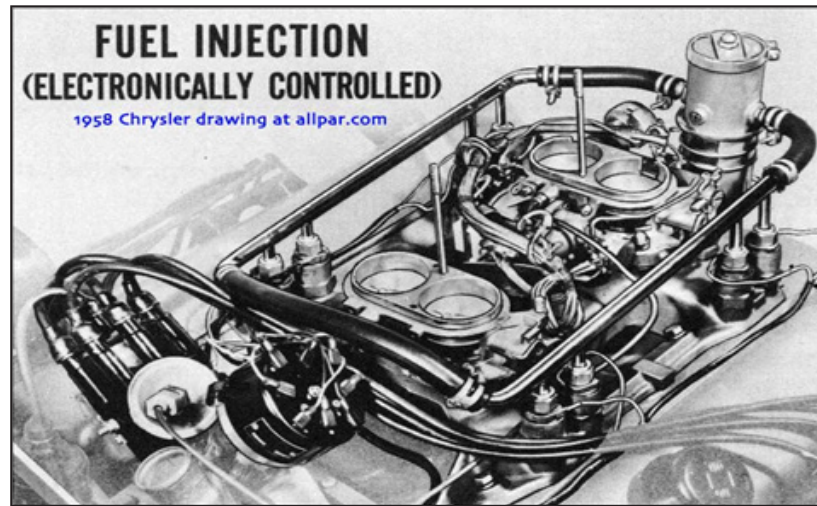
Bosch developed an electronic fuel injection system, called D-Jetronic (D for Druck, German for “pressure”), which was first used on the VW 1600TL/E in 1967. Bosch superseded the D-Jetronic system with the K-Jetronic and L-Jetronic systems for 1974, though some cars (such as the Volvo 164) continued using D-Jetronic for the following several years.

The Cadillac Seville was introduced in 1975 with an EFI system made by Bendix and modelled very closely on Bosch’s D-Jetronic.

In Japan, the Toyota Celica used electronic, multi-port fuel injection in the optional 18R-E engine in January 1974.

The limited production Chevrolet Cosworth Vega was introduced in March 1975 using a Bendix EFI system with pulse-time manifold injection, four injector valves, an electronic control unit (ECU), five independent sensors and two fuel pumps.

GASOLINE DIRECT INJECTION



With permission from Allpar.com

TERMINOLOGY

SINGLE POINT – (ALSO CALLED TBI) (WET MANIFOLD) (GM-EARLY 80'S, THEN OTHERS)

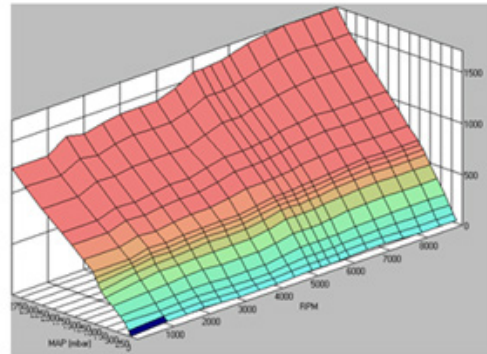
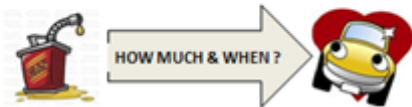
CONTINUOUS – (J-TRONIC) – NO PULSES – CONTINUOUS FUEL FLOW TO INJECTORS – MOST AIRCRAFT USE THIS TYPE

CENTRAL PORT – GM 1992-96 – CPI- USES POPPET VALVES AND AN INJECTOR BLOCK (4.3L , 5.0L & 5.7L) CAN BE EITHER “BATCHED” or SEQUENTIAL

MULTI PORT – CONTINUOUS or ”BATCHED” or SEQUENTIAL – INJECTORS JUST BEFORE INTAKE VALVE. MANIFOLD IS ONLY SLIGHTLY “WET”. USED FOR YEARS BETWEEN TBI & DIRECT SYSTEMS

DIRECT – USES A COMMON RAIL- INJECTORS DELIVER FUEL DIRECTLY INTO THE COMBUSTION CHAMBER-SOMETIMES ON THE INTAKE STROKE AND SOMETIMES ON THE COMPRESSION STROKE. VERY HIGH PRESSURES ARE INVOLVED – EMERGING TECHNOLOGY

THE AMOUNT OF
Fuel
is determined by engine
operating conditions



THE ECM USES A FUEL MAP & CALCULATIONS
BASED ON SEVERAL INPUT SIGNALS.

CARB, TBI or MPI
*interchangeable on
the same engine ??*

WHY??

GDI unique system design

SAFETY

**WARNING: THE NEXT SLIDE IS
VERY GRAPHIC!!!**

**Absolutely important to follow all OEM safety
procedures when working on GDI systems**

- 1- System residual pressure bleed down procedure
- 2- Breaking into the high pressure system for service
- 3- Some components are designed for a "one time" use.
If service is required, they must be replaced
- 4- Torque values are very important to prevent damage

GASOLINE DIRECT INJECTION

UNIQUE THINGS ABOUT GDI

- 1- _____
- 2- _____
- 3- _____
- 4- _____
- 5- _____
- 6- _____

GDI **GASOLINE DIRECT INJECTION**

This changes everything

WHY DID MANUFACTURERS CHANGE TO GASOLINE DIRECT INJECTION

CHANGES IN GOVERNMENT EMISSION LAWS (CO₂)

CHANGES IN FUEL CAFE RATINGS (35.5 IN 2016)

INCREASED DIESEL EMISSION SOOT & NO_x REQMNT's

**GDI ATTEMPTS TO COMBINE THE ECONOMY & POWER OF A DIESEL
WITH THE REDUCED NOISE LEVEL OF A GAS ENGINE APPROACHING
THE FUEL ECONOMY OF A HYBRID**

GASOLINE DIRECT INJECTION

ADVANTAGES OF GASOLINE DIRECT INJECTION

- 8-22% higher fuel economy
- More torque and horsepower allowing smaller engines
- Can inject fuel anytime during the 4-stroke cycle of events
- Cylinder scavenging is greatly enhanced
- Compression ratios can be higher
- Leaner fuel mixtures during cold engine operation
- Adjustable fuel modes to target emission problems
- Lower CO₂ emission levels
- Reduced engine pumping losses
- Cylinder charge cooling
- Much smaller droplets spray of fuel
- Reduced cylinder wall temperatures (A/C theory- high pressure liquid changing to a low pressure gas)
- Spark knock is much more controlled

DISADVANTAGES OF GASOLINE DIRECT INJECTION

- Dramatic changes in the fuel delivery and control systems
- Small injection time window (sometimes in micro-sec.)
- Lean burns make post combustion NO_x difficult to control
- High levels of soot (carbon) formation due to lower intake temps & exhaust inversion
- Increased electrical power demands for injectors
- Proper engine maintenance is very critical
- Components can be more expensive
- Newer technologies require technician training
- Many components are “one-time” use. (Seals, HP line, etc)
- Fuel rail and lines are made from stainless steel
- Has many “special tools” needed for routine service

Ford 1.0L Ecoboost video link: <https://www.youtube.com/watch?v=SaUDNhS1nrg>

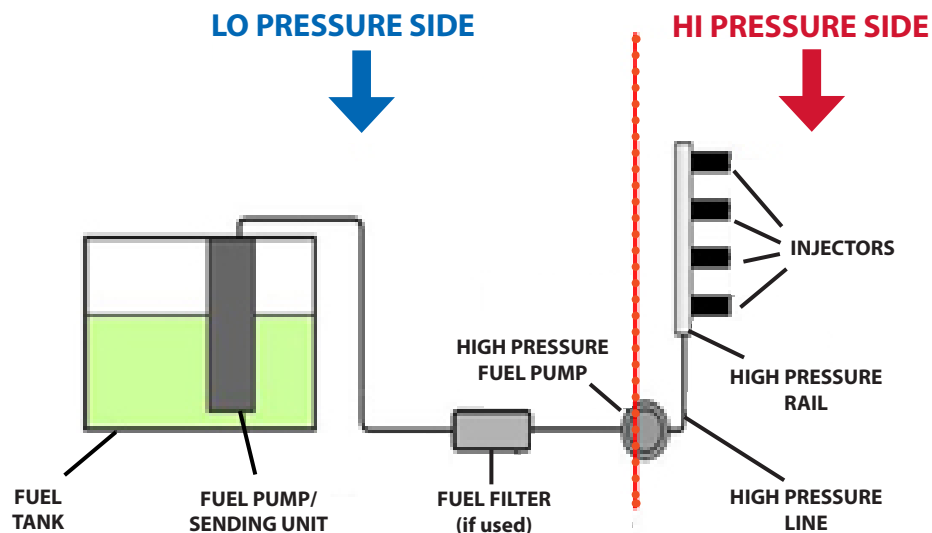
GASOLINE DIRECT INJECTION

What new technologies did we just hear??

- 3 cyl. 1.0 LITER engine generating 125 horsepower
- Split cooling system
- Variable valve timing on intake & exhaust
- Dramatic piston shape changes
- Camshaft drive belt submerged in oil
- Increased valve overlap to improve scavenging
- Reduced turbo lag due to scavenging & gdi
- Multiple injections in the same firing event
- Integrated exhaust manifold with cylinder head
- Offset crankshaft to piston axis
- Two stage oil pump
- Gasoline direct injection

SO WHAT IS GDI ALL ABOUT??

Gasoline Direct Injection



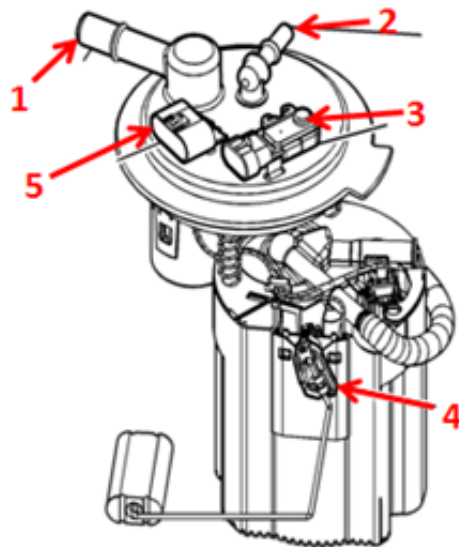
GDI MAIN COMPONENTS

GASOLINE DIRECT INJECTION

LOW PRESSURE SIDE OF SYSTEM:

IN-TANK FUEL PUMP:

- Similar to port fuel systems
- PWM speed controlled which varies output pressure
- Can be brushless
- Usually part of a module with sending unit, pressure regulator and pump
- Can have an EVAP tank pressure sensor & a mid-pressure fuel pressure sensor
- Returnless in most cases and can have built in or separate filter
- Usually has four wires: Pump B+ and ground, sending unit + and ground



1. Fill Limit Vent Valve
2. Fuel Feed Pipe
3. Fuel Tank Pressure Sensor
4. Fuel level Sensor
5. Fuel Pump Electrical Connector

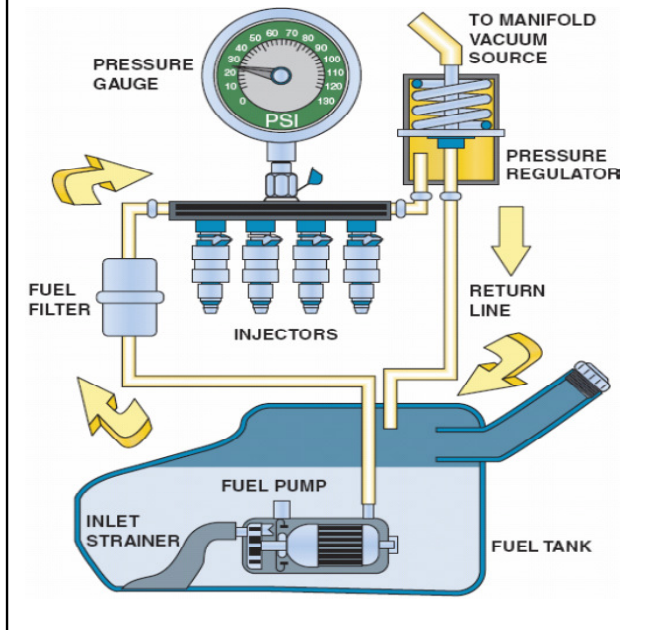
nothing new here...

FUEL LINES AND HOSES:

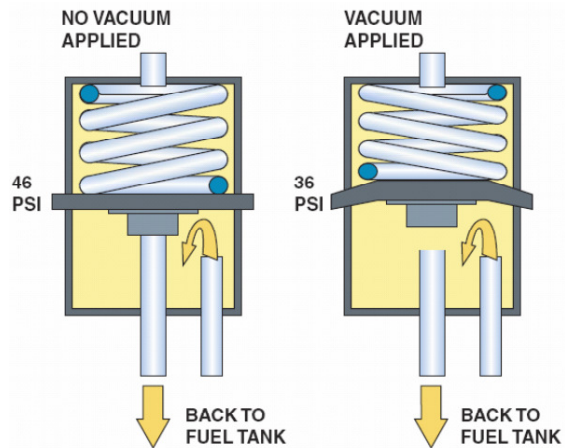
- Still the same as port fuel systems
- Various quick connect fittings from different OEM's
- Made from nylon, plastic and other materials
- Can be serviced and repaired
- Often contains a service port for pressure testing
- Can also have a pulse damper built into low pressure line

GASOLINE DIRECT INJECTION

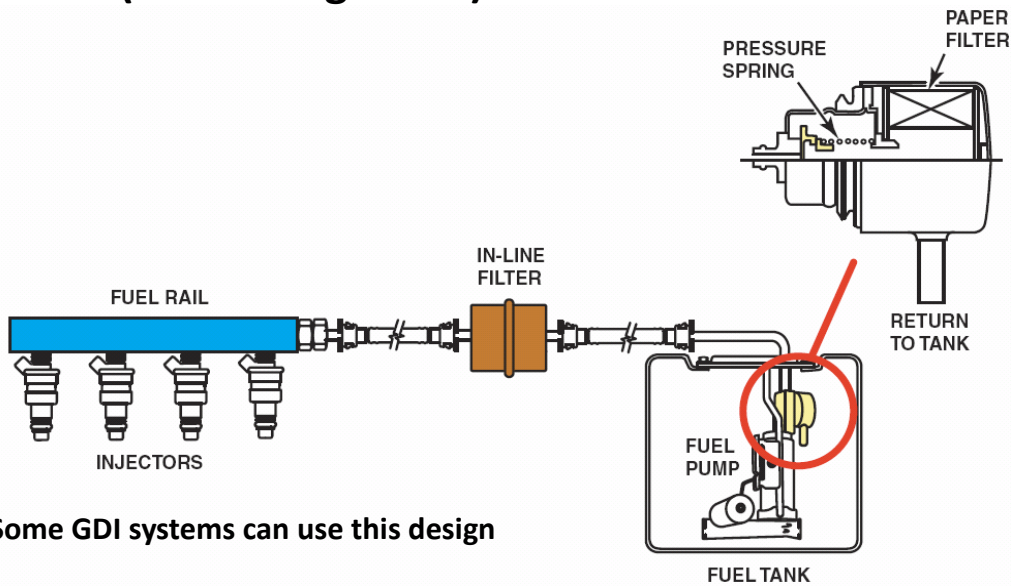
Port Fuel Injection vacuum based pressure regulator with return line.



Vacuum Pressure Regulator Review



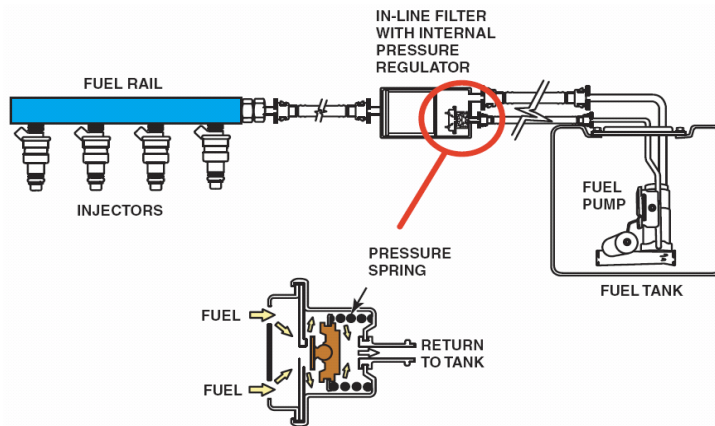
Port returnless system with in-tank regulator (in tank regulator)



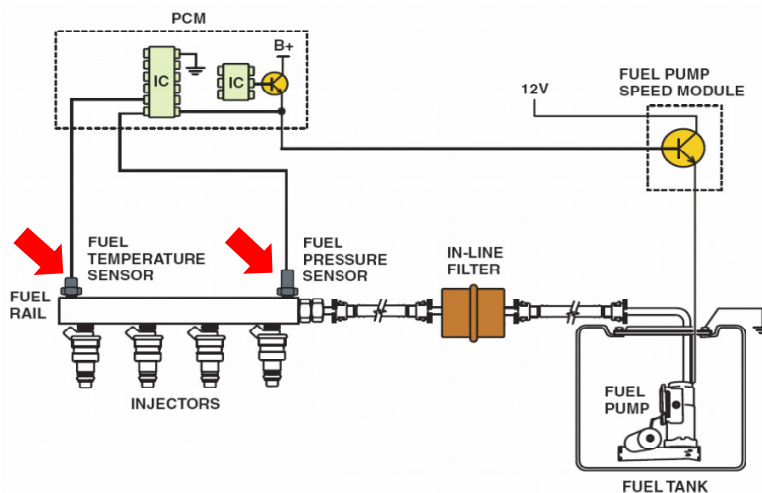
Some GDI systems can use this design

GASOLINE DIRECT INJECTION

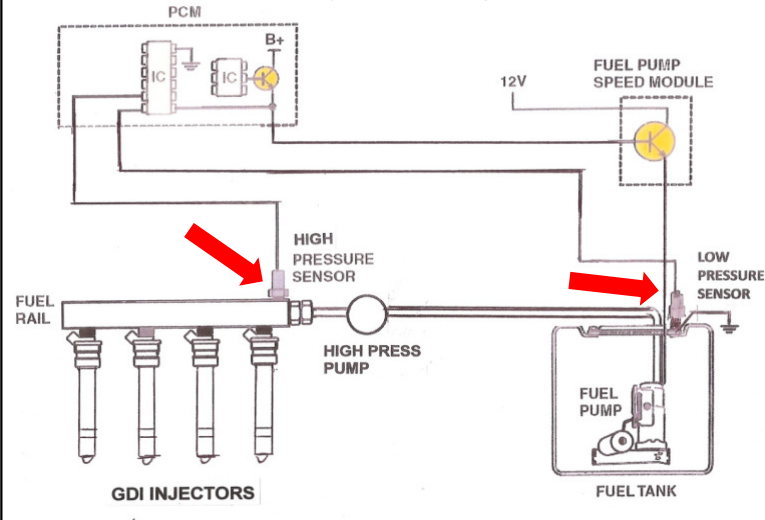
Port returnless system with fuel regulator inside fuel filter (GM-Ecotec)



Port return-less system with PWM controlled fuel pump



GDI return-less fuel pressure regulation with PWM



GASOLINE DIRECT INJECTION

HIGH PRESSURE SIDE OF SYSTEM:

HIGH PRESSURE FUEL PUMP

- Driven by a 2, 3 or 4 lobe on camshaft.
- Can be one or two on a V engine
- Usually held in place with two bolts (bolts are “one-time” use)
- Can have a roller, follower or bucket type drive riding against cam lobe
- Must be “timed” when installing
- Capable of pressures from 500-3000 psi
- Contains an electric pressure regulator solenoid controlled by PCM
- Contains an internal pressure relief valve
- “Clicking” sound is normal
- Will default to either low or high pressure when connector is unplugged depending on OEM



HIGH PRESSURE FUEL LINES & RAIL

- Made from stainless steel for strength and corrosion resistance
- Called a “common rail” much like diesel engines
- Injectors are attached to rail with special clips/retainers (“one-time” use)
- Rail also contains a high pressure sensor (electric)
- No service port for pressure testing
- Line from HP pump to rail often uses “ball type” fittings (“one-time” use)
- Most HP lines are “one-time” use only and must be replaced when serviced
- Rail is usually bolted in place to cylinder head
- Rail/Injectors can be “buried” under the intake manifold

GDI Fuel Delivery

- 1- Port fuel injection uses injector pulse width to control fuel delivery. Average – 1.5ms to 3.5ms
- 2- GDI uses high pressure to control fuel delivery. Avg. injector pulse width = .4ms (400 micro-seconds!)
- 3- To accomplish this, the HP pump must be able to react very quickly to fuel delivery changes.
- 4- The PCS (pressure control solenoid) can be duty cycled at an average of 4700 cps. (OEM's can differ)
- 5- GDI pressures can range from 500 psi @ idle to near 3,000 psi at high engine loading. (OEM's can differ)

GASOLINE DIRECT INJECTION

FUEL INJECTORS

- Can be of two types: Solenoid and Piezoelectric (most common is solenoid)
- Solenoid type operates with voltages of 50-60V to open the valve, then 12V to stay open
- Voltages are generated by PCM using a DC/DC converter and capacitors
- Piezo injectors are a stack of crystals that open a valve. Most operate with voltages around 105 V
- Both B+ and ground are connected to PCM.
- Have Teflon seals where injector goes into the cylinder heads. “one-time” use and must be properly sized with special tools when replacing.
- Tips can be a series of holes or a single slot. GDI injectors have 10-20µm (micron) size
- Usually located between intake valves or directly on top of the cylinder head
- Do not use “noid-lites” or 12 volt test lights on GDI fuel injectors (high voltage shock hazards)

PORT INJECTION SYSTEMS COMPARED WITH GDI SYSTEMS

ITEM	PORT	GDI
Fuel pressure	35-60 psi	low – 50-70 psi high – 500-2900 psi
PW @ idle	1.5 – 3.5 ms	About 0.4ms (400 us)
Injector resistance	12 – 16 ohms	1-3 ohms
Injector voltage	6V-12V (lo/hi resis)	50-90V then 12V
# of injections per event	one	1-3
Engine comp. ratio	8:1 – 11:1	11:1 – 13:1

INJECTOR SPRAY PATTERN DESIGNS

- Wall guided swirl combustion (injector in side of cylinder head)
- Spray guided (injector in top of cylinder head)
- Wall guided “tumble” combustion (piston shape creates a tumbling affect as it moves up)

PISTON SHAPES

- Many GDI engines use special shaped piston tops to create desired turbulence or concentration of fuel

GDI COMBUSTION MODES

GDI COMBUSTION OPERATING MODES

- | | |
|--------------------------|----------------------|
| • Homogeneous | • Stratified |
| • Homogeneous lean | • Wide open throttle |
| • Homogeneous ultra-lean | • Clear flood (WOT) |

HOMOGENEOUS

Definition of Homogeneous Mixture: A **mixture** which has uniform composition and properties throughout. For example, air is a **homogeneous mixture** of gases. A teaspoonful of table salt stirred into a glass of water also makes a **homogeneous mixture**.

All previous Carb, TBI and PORT systems used homogeneous mixtures.

STRATIFIED

Stratified charge engine may be defined as an engine in which **fuel** is injected in combustion chamber during the end of the compression stroke and just before the burning of the charge. In Compression Ignition engine, first of all the air is compressed after the intake stroke.

Not all GDI engines use stratified injection. Used during idle and periods of “no-load”. Extremely lean mixtures. 40-60 : 1. Some European and Asian vehicles use stratified mode injection.

GASOLINE DIRECT INJECTION

GDI MAINTENANCE, TESTING & SERVICE

1. Correct OEM maintenance is critical to GDI engines. Always follow OEM recommendations.
2. Using proper fluids and lubricants is crucial. Use ONLY OEM recommended oils and lubricants to avoid expensive repairs or warranty rejection issues.
3. Most OEM's recommend using top-tier gasoline. www.toptiergas.com Try to use top-tier fuel whenever possible. Avoid purchasing gas from a station that has recently been filled with a tanker truck.
4. Many OEM's recommend periodic fuel system cleaning with additives. Use Techron or equivalent.

GDI PROBLEMS

1. Accumulation of carbon deposits on intake valves and on injector tips (exhaust inversion & PCV oil).
2. Lack of maintenance by owners. Most common cause of GDI problems.
3. Using poor quality fuel. Will cause deposits and injector fouling. Also can cause driveability problems with poor burning or flame propagation.
4. Injectors plugging up creating driveability problems. Short cold engine driving and poor quality fuel are causes.
5. HP pump failure due to lack of maintenance and wrong engine oil used. Always change oil and filter according to OEM specifications and NEVER use "off-brand" or "cheap" oils or filters.
6. High NOx levels during lean operation.

SERVICE PROCEDURES

1. DEPRESSURIZATION before service. Always follow OEM recommendations.
2. Can remove fuel pump relay and run engine till it stalls.
3. Can depressurize using scan tool with bi-directional control.
4. Always confirm no high side pressure before disassembling system. Use scan tool to measure.
5. Importance of using scan tool for proper diagnosis as access to some GDI components often involve major engine disassembly.
6. Some service information says to wait at least two hours before opening up the high side system. Always check with scan tool for pressure reading before disassembly.

LOW PRESSURE SYSTEMS MAINTENANCE & REPAIRS

1. Low pressure fuel filter replacement (if used). Serviceable fuel filters are now used less than before due to new government regulations especially in California.
2. Low pressure fuel lines & pump module.
3. Low pressure test port and/or low pressure sensor (if used).
4. Some vehicles have a pulse dampener.
5. Low pressure DTC's and scan tool use.
6. Basically the same as port fuel systems.
7. Importance of proper service information.
8. Always check for TSB's prior to service.

GASOLINE DIRECT INJECTION

HIGH PRESSURE SIDE SERVICE PROCEDURES:

1. Replace HP pump – common failure (need new bolts/seal/gaskets).
2. Replace HP pump follower (bucket) and also cam if worn.
3. Remove fuel rail w/injectors (often requires special tools).
4. Replace injectors (includes sizing of Teflon seals with special tools. Cannot be reused.
Replacing injectors also requires new retaining clips/O-rings and seals.
5. Replace HP pressure sensor (simple R& R after depressurization) (always follow OEM procedures).
6. De-carbonizing intake manifold and injector cleaning.
7. Remember that the HP connecting line from the HP pump to the rail is a “one-time” component and must be replaced anytime it is removed. (ball fitting ends).

SCAN TOOL DIAGNOSTICS

Name	Value	Unit
<input type="checkbox"/> Desired Fuel Rail Pressure	3.99	BAR
<input type="checkbox"/> Fuel Pressure Sensor LOW SIDE	54.4	psi
<input type="checkbox"/> Fuel Rail Pressure Sensor HIGH SIDE (EQUAL TO 520 psi)	35.86	BAR
<input type="checkbox"/> Fuel Rail Pressure Sensor	1.14	V
<input type="checkbox"/> Engine Speed	594	RPM
<input type="checkbox"/> Desired Idle Speed	600	RPM
<input type="checkbox"/> ECT Sensor	179	°F
<input type="checkbox"/> IAT Sensor	118	°F
<input type="checkbox"/> MAF Sensor	0.01	lb/s

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REMEMBER THAT THERE ARE 14.5 PSI IN ONE BAR OF PRESSURE.

- Use scan tool bi-directional control to turn components ON/OFF for testing and function.
- Use scan tool to interpret DTC's and always follow OEM diagnostic procedures for each DTC.
- Become familiar with GDI scan tool PID's as there are many more than with port fuel systems.
- Always obtain and use all required special tools when working with GDI components. Failure to do so will almost certainly result in expensive component damage, dangerous fuel leaks and personal injury.

REMEMBER THAT NOT ALL “FLEX-FUEL” CARS ARE BADGED AS SUCH ON THE OUTSIDE OF THE BODY.

Some other available systems used on GDI

- Cylinder deactivation on demand
- Intake & Exhaust cam phasing (VVT)
- Variable valve lift (2-step lifter)
- Ion knock sensing and spark control (current)
- Electronic tuned active intake manifold runners
- Multi-spark ignition system
- Torque management system (transmissions)
- Electronic turbo wastegate system
- Wide-band oxygen sensor
- Exhaust temperature sensor
- Both speed/density and air meter system used

What other things can we do with GDI??

- Get catalytic converter hot right now (injection pulse on exhaust stroke)
- Starter-less engines?
- Better emission control
- Much quicker and constant fine tuning of fuel delivered (injection pulse in micro-seconds)

GASOLINE ENGINES WITH COMPRESSION IGNITION?

HYUNDAI, GM & others are both working on one. "GDCI" "HCCI" "PPCI"

- No throttle plate (eliminates pumping losses)
- Has both a turbocharger and a supercharger. Super is used at low speeds, then switches to turbo at higher engine speeds
- 14.8 : 1 compression ratio
- 500 Bar fuel pressures (that's 7,250 psi!!!)
- Cold start intake heaters
- Specialized variable valve train. Special exhaust cam lobe to admit exhaust gas back into intake for heating purposes
- Switchable piston coolers
- Lower NOx emissions and no NOx converter needed
- Multiple injections per combustion cycle (Why?)
- Can have spark plugs (GM), but used for idle and WOT only
- Can have a 15% increase in fuel economy

GASOLINE DIRECT INJECTION

WIDE BAND OXYGEN SENSORS

Wide Band Oxygen Sensors have been used on vehicles since around 1992 when Honda first came out with one. Now, most all vehicle manufacturers used them primarily for the following reasons:

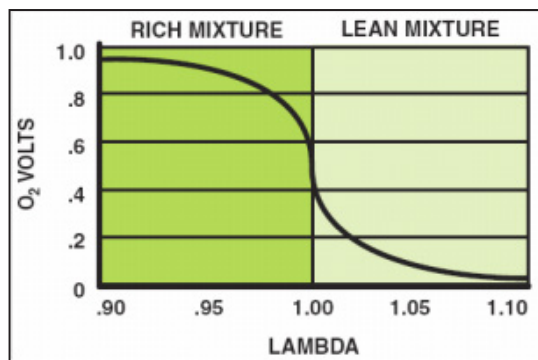
- More stringent exhaust emission requirement standards.
- Gasoline direct injection systems require very fast and accurate exhaust gas oxygen content measurement. Not all GDI cars use wide-band O_2 sensors. Only SULEV rated vehicles.
- Wide Band O_2 's operate from between 10-30 times faster than older types.

Wide Band O_2 's can be called by many names with the following the most common examples:

- Wide-band oxygen sensor
- Wide-range oxygen sensor
- Lean air-fuel sensor (LAF)
- Broadband oxygen sensor
- Air-fuel ratio sensor (AFR)
- Air-fuel sensor (AF)
- Wide range air fuel sensor (WRAF)

Why do we need them?

Older style zirconia oxygen sensors reacted to air fuel mixtures that were either richer or leaner than “stoichiometric” which is 14.7:1. Therefore, these sensors cannot actually determine the exact air fuel ration, but is constantly “crossing over” the stoichiometric range from rich to lean.



As EPA increased exhaust emission requirements such as NLEV (natural low emission vehicle), ULEV (ultra low emission vehicle) and SULEV (super ultra low emission vehicle). The newer fuel management systems that the manufacturers were forced to develop required much more accurate fuel control than could be provided by the older zirconia type O_2 's.

What can a wide-band O_2 do?

Comparing a newer wide-band oxygen sensor with the older zirconia type:

1. The wide-band system improves cold start performance and can become “active” within 10 seconds.
2. Wide-bands are able to measure fuel air ratios from as lean as 23:1 to as rich as 10:1.

GASOLINE DIRECT INJECTION

REVIEW OF OLDER ZIRCONIA OXYGEN SENSORS:

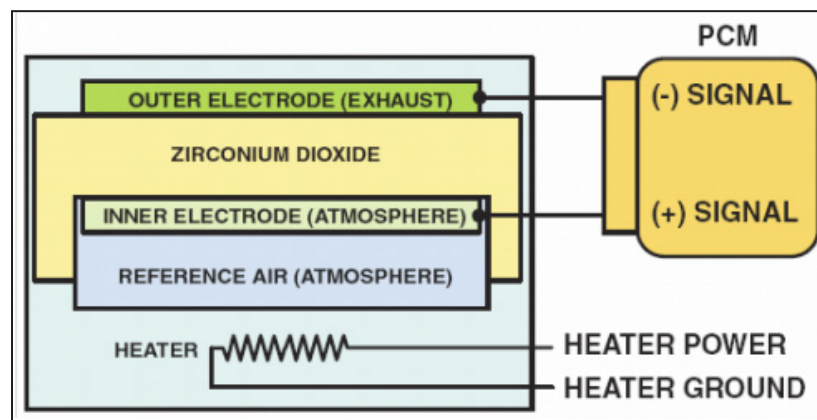
1. Able to only detect “rich” or “lean” above or below 14.7:1.
2. Called “narrow-band” or “two-step” sensor as it can read only rich or lean.
3. The “middle voltage value” of a zirconia sensor is 0.450V or (450mv).
4. Above 0.450V is a rich mixture (very little oxygen).
5. Below 0.450V is lean mixture (lots of oxygen).

Many technicians get confused about zirconia oxygen sensors especially when dealing with “rich” fuel mixtures. For example, if a cylinder loses a spark plug, the resulting fuel mixture is very rich because the fuel/air wasn’t ignited. However, because the O_2 cannot sense fuel, it only sees the unburned oxygen and sends a low output voltage to the ECM which in turn adds more fuel to the cylinder by increasing the injector pulse width. Remember, a zirconia oxygen sensor can only “sense” oxygen and not fuel.

A zirconia oxygen sensor can have 1, 2, 3, or 4 wires depending on the vehicle and system. O_2 ’s are placed in the exhaust gas stream both before and after the catalytic converter on most engines. Newer single-band O_2 ’s can have an electric heater built inside that is designed to shorten the time needed to heat the sensor high enough for it to start working. Most agree that it must reach a temperature of at least 600 °F (320 °C) before it can operate efficiently and accurately. This takes time and the engine is most often running in “open loop” during this time. Open Loop does not provide efficient fuel/air ratios for clean catalytic converter operation and emissions.

NERNST CELL

Another term used to describe a zirconia oxygen sensor is a Nernst Cell. This term was named for Walther Nernst, a German physicist who worked in electrochemistry in the late 1800’s and early 1900’s.

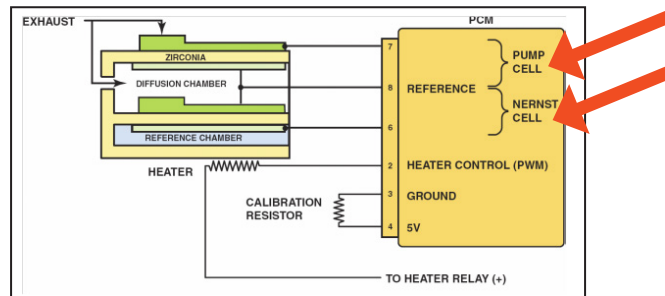


A conventional zirconia (planar type) oxygen sensor with four wires

GASOLINE DIRECT INJECTION

WIDE BAND OXYGEN SENSORS:

A dual-cell wide-band oxygen sensor has a “bias voltage” sometimes called a reference voltage that is applied to two different platinum electrodes. Technically, oxygen ions can be pumped from the air side of the sensor to the exhaust side and/or if the sensor polarity is reversed, the oxygen ions can move in the opposite direction. There are two internal chambers in a dual-cell planar type wide band sensor. One is called the pump cell and the other is called the Nernst cell. The two cells have a common ground called “reference”. See below figure.



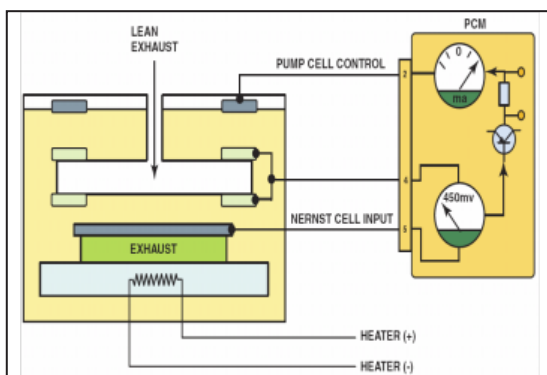
The basic and very simplified explanation of how a wide-band planar type sensor works is that it uses both a positive or negative voltage signal to keep a balance between the two internal sensors. Oxygen sensors do not actually measure “oxygen” in the exhaust stream, but instead they produce a voltage this is based on the ion flow between the platinum electrodes of the sensor which is used to maintain a stoichiometric balance.

There are two internal chambers in the wide-band oxygen sensor. One is called the diffusion chamber and is exposed to exhaust gases. The other is called the reference chamber and is exposed to ambient air. A wide-band sensor uses a positive or negative voltage signal to keep a balance between the two sensors.

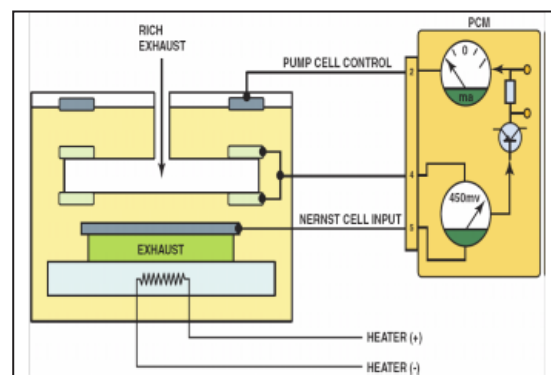
EXAMPLES:

If there was a rich exhaust, the ion flow is increased to help maintain balance between the ambient air side and the exhaust side of the sensor.

If there was a lean exhaust, there is oxygen in the exhaust and the ion flow from the ambient side to the exhaust side would be low.



LEAN EXHAUST CONDITION



RICH EXHAUST CONDITION

GASOLINE DIRECT INJECTION

The PCM is capable of supplying a small current (less than 20 milliamps) to the pump cell electrodes, which causes the oxygen ions to travel through the zirconia into or out of the diffusion chamber. The PCM pumps O_2 ions in and out of the diffusion chamber to bring the voltage back to 0.450 volts, using the pump cell.

DIAGNOSIS OF WIDE BAND OXYGEN SENSORS:

Wide band oxygen sensors are diagnosed similarly to narrow band sensors. Observe scan tool data and confirm “activity” while looking at oxygen sensor voltage. Observe the Lambda reading to observe condition of exhaust gas.

RESISTANCE MEASUREMENT:

Some OEM’s give procedures for measuring the resistance of the “calibrating resistor” that is usually located in the wiring harness. Be sure to check service information for the proper wire color, location and terminal identification. An open resistor will read “infinity”, “OL” or ∞ . If shorted, the resistor will read “0” or close to zero.

VOLTAGE MEASUREMENT:

OEM manufacturers often use different reference voltages but they range between 2.2 and 3.6 volts with most remaining constant at around 2.5 volts. Certainly there are exceptions and one must consult OEM service information before testing and evaluating voltage readings. Some scan tools will display “older” narrow band voltage readings and some will give Lambda readings. See LAMBDA below for further explanations.

AMPERAGE MEASUREMENT:

You can measure the amperage in the pumping circuit to confirm sensor operation and determine a rich/lean condition, but if the scan tool does not display this information, most technicians do not perform this test. Remember that a negative current flow equals LEAN exhaust condition and a positive current flow indicates a RICH exhaust condition.

What is LAMBDA?

Lambda is a reference number that is displayed on modern scan tools to reference the condition of the exhaust gas. Lambda is NOT a voltage, but a reference. Lambda 1 is equal to a stoichiometric mixture of 14.7:1. Any number higher than one indicates a lean mixture and a number less than one indicates a rich mixture.

LAMBDA REFERENCE CHART		
1.7 - EQUALS 24.99:1	A/F RATIO	70% LEAN
1.5 - EQUALS 22.05:1	A/F RATIO	50% LEAN
1.3 - EQUALS 19.11:1	A/F RATIO	30% LEAN
1.2 - EQUALS 17.64:1	A/F RATIO	20% LEAN
1.1 - EQUALS 16.7:1	A/F RATIO	10% LEAN
1.0 - EQUALS 14.7:1	A/F RATIO	
0.9 - EQUALS 13.23:1	A/F RATIO	10% RICH
0.8 - EQUALS 11.76:1	A/F RATIO	20% RICH
0.7 - EQUALS 10.29:1	A/F RATIO	30% RICH
0.5 - EQUALS 7.35:1	A/F RATIO	50% RICH
0.3 - EQUALS 4.41:1	A/F RATIO	70% RICH



GASOLINE DIRECT INJECTION

SCAN TOOL READOUT & PID's:

Most service information directs the technician to use a factory level scan tool to test wide-band oxygen sensors because the PCM can perform sensor tests and display results. The wide-band oxygen can also be fooled like the narrow-band sensor with “unmeasured” air occurring from an exhaust manifold leak or other faults. Global scan tools will often display different data than factory level scan tools. Typical scan tool readings (factory) would be:

HOS21 – +269 mA	If the current is positive, it is indicating that the PCM is pumping current into the diffusion gap primarily due a rich exhaust condition. Negative amperage readings indicate a lean exhaust condition.
Air-Fuel Ratio	The air/fuel ratio is usually expressed with a Lambda number. Remember that “1” is stoichiometric (14.7:1) and numbers higher than 1 indicates a lean exhaust and numbers lower than 1 indicate a rich exhaust condition.

OSCILLOSCOPE:

Wide-band oxygen sensors are best tested with an oscilloscope. Observe the waveform, use freeze frame, zoom and various time base and voltage adjustments to record and single out abnormal pattern variations.

DIAGNOSTIC STRATEGIES:

Are the wide-band oxygen sensor readings abnormal because of defective sensor or an engine running condition?

1. Diagnosis of wide-band oxygen sensors is very similar to narrow-band sensors except that oscilloscope testing can reveal problems that scan tools cannot. This is primarily because of the quicker speed at which wide-bands react to changes in exhaust gas conditions.
2. Use “flight record” on scan tools to capture glitches and sensor problems.
3. Wide-Band O_2 's have a pattern failure primarily with the internal heater circuits and the grid failure on which the heater is mounted. Engine mis-fires, “hiccups” and back-fires can take out a wide-band quickly. Always check for DTC's when testing problems.

GASOLINE DIRECT INJECTION

ELECTRONIC THROTTLE CONTROL (ETC)

Newer vehicles now come equipped with Electronic Throttle Control. This means that the old style of using mechanical linkage (rods or cables) is now replaced with an electric motor actuator mounted to the throttle body which can move the throttle shaft in either direction to close or open the throttle. The accelerator pedal now has an electric “accelerator pedal position sensor” or APP attached to it which informs the controller of the position of the pedal.

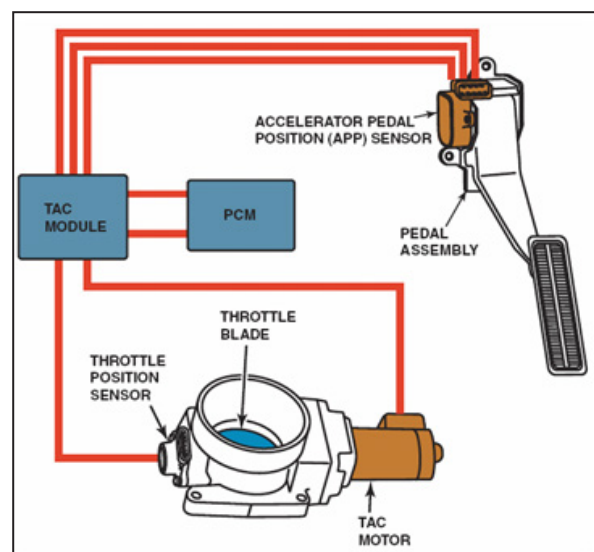
ETC has some advantages and a few disadvantages over the older linkage style system.

ADVANTAGES:

- ETC does away with the need for cruise control actuators and modules. The cruise control can function from just the ETC components.
- It can be used to delay the transfer of torque via shifting points to the transmission which improves shifting and driveability.
- Reduces the amount of “hardware” and the number of moving parts.
- Allows throttle plate to open at highway speeds for greater fuel economy and a large reduction in “pumping losses. The PCM can open the throttle at highway speeds, yet while maintaining a lean fuel mixture due to GDI. It then allows EGR to open more for additional pumping loss reduction.
- Can be used to improve smooth engine operation during rapid acceleration.
- ETC eliminates the need for having an IAC (Idle Air Control) system.

Electronic Throttle Control (ETC) can also be called Drive-By-Wire by some OEM’s, but most use the term ETC. A typical ETC system contains the following components:

- An accelerator Pedal Position Sensor
- A servo-motor or actuator attached to the throttle body
- A control module or controller responsible for moving the servo-motor or actuator
- Wiring between components
- A Throttle Position Sensor attached to the throttle body assembly



GASOLINE DIRECT INJECTION

THE “DRIVING FEEL” OF AN ETC SYSTEM:

An ETC equipped vehicle is similarly driven as conventional linkage vehicles with the following exceptions:

- There may not be an immediate change in engine speed if the throttle pedal is depressed while in PARK.
- During rapid acceleration, there may be a slight delay before the engine responds. This gives the PCM time to deliver the correct amount of fuel to the engine.
- If engine speed does increase with pedal depression during PARK, most systems limit engine speed to around 2,000 RPM's.
- During cruising speeds, the accelerator pedal may move up or down without any changes in engine speed.
- Some systems eliminate the ability to do “burnouts” due to engine speed versus road speed comparisons.
- Commanded torque versus “delivered” torque.

Some Hondas and early 2000's Dodge trucks have a “cable” attached to the gas pedal. Although confusing, the cable only operated the APP sensor and did not cause the throttle plate to open.

ACCELERATOR PEDAL POSITION SENSOR:

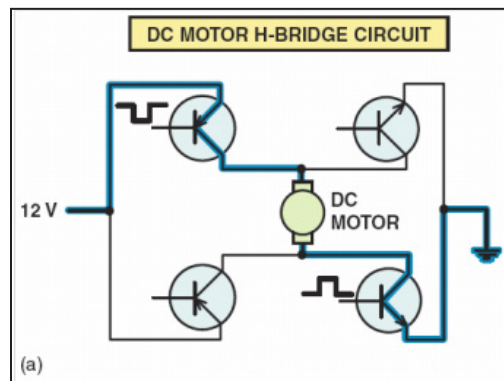
Perhaps the most critical sensor of the entire ETC system is the accelerator pedal position sensor (APP). The APP can have 1, 2 or even 3 separate or integral position sensors designed to give a very accurate signal to the ETC module regarding pedal position. Some systems also have “feedback” circuits to provide diagnostic information and redundant checks for proper operation.

- Can be a Hall-Effect or a common 3-wire position sensor (TP type).
- Usually has two position sensors attached. They give opposite voltage signals (one goes up and one goes down) during accelerator pedal position changes.
- The common sensor type (3-wire) usually has a voltage range of .5-4.5V. One would show .5V at closed throttle and the other would show 4.5V. They would inversely change voltages as the pedal is moved.

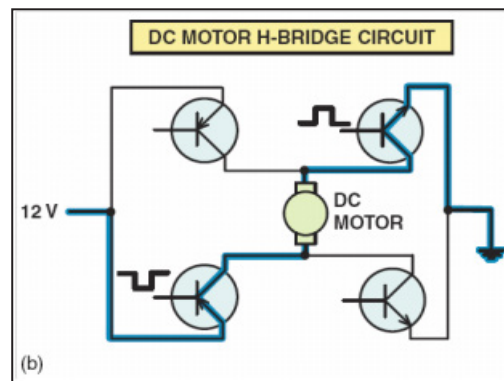
ETC THROTTLE BODY:

- Contains the electric motor that operates the throttle plate.
- Electric motor is a DC type and is often called a servo motor.
- Contains two throttle position sensors (TP) that feeds back the position of throttle plate to the PCM or TCM.
- Contains a reduction gear assembly and a return “clock spring” that returns the throttle plate to its “default” position which usually equates to an engine speed lower than 1,200-1,500 RPM's. (16%-20% open).
- Often contains a special coating from OEM that can be destroyed by using some cleaners.
- Pattern failure includes stripped gears and corrosion caused from moisture entering gear housing.
- The electric motor uses an H-bridge circuit to reverse the polarity of the servo motor.

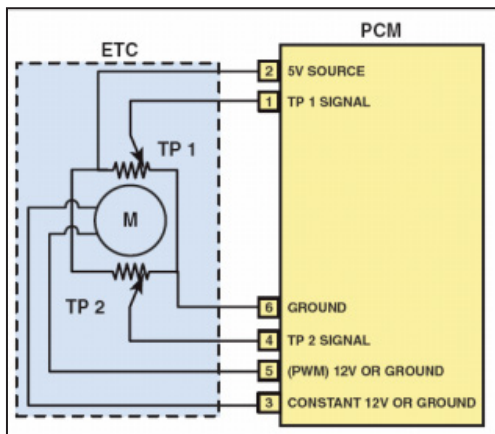
GASOLINE DIRECT INJECTION



ONE DIRECTION POLARITY



OPPOSITE DIRECTION POLARITY



Terminal # 3 is always "constant" whether it be positive or ground.

Terminal # 5 is always Pulse Width Modulated whether it be positive or ground.

Both terminals are switched by the control module. This reverses the motor polarity and thus the direction of rotation.

GASOLINE DIRECT INJECTION

GDI VIDEO LINKS

<https://youtu.be/n-KW5GH6NfY> — GDI NOx catalyst issues & false codes — 5:11

<https://youtu.be/rRHPSxMvia4> — PCV Catch Can DIY (Home Depot) — 1:54

<https://youtu.be/0oE9JCmsxeg> — GM Ecotec GDI explanation- includes service — 14:04

<https://youtu.be/KIVdPaTSot8> — Basic explanation of GDI system — 2:47

<https://youtu.be/qd90yHlmsS4> — Basic GM explanation — 1:44

<https://youtu.be/LjJSbHxIvnM> — Bosch GDI systems explanation — 8:26

<https://youtu.be/4M9BITr1zhg> — GDI HP pump construction — 4:28

<https://youtu.be/IzXeeCiSL7k> — GDI injection failures — 3:51

https://youtu.be/MPUxL9HhP_E — GDI Fuel pressure sensor — 4:02

<https://youtu.be/4FG8tSWrCI8> — GDI Injector operation — 4:28

<https://youtu.be/H6p0sVdMeeQ> — GDI vs PFI comparison — 3:37

<https://youtu.be/hHmM4hO9IP8> — Hyundai Lambda V6 GDI engine — 3:08

https://youtu.be/Lt_6uz_7A08 — Kia/Hyundai 1.6L GDI engine — 4:14

<https://youtu.be/hybKYFUOs3Q> — Overview of GDI — 5:49

<https://youtu.be/QBXszI4-570> — GDI Advantages — 2:52

<https://youtu.be/zTrNSsZvhLw> — GDI Spray guided injection — 5:01

<https://youtu.be/zQKwdYKlcpq> — GDI Wall guided injection — 2:28

<https://youtu.be/gvRuUm7Tzk0> — GDI HP Pressure control — 2:18

<https://youtu.be/4M9BITr1zhg> — GDI HP Pump construction — 4:28

<https://youtu.be/XK7I37LLda8> — GDI HP Pump — 3:43

<https://youtu.be/ewqVvue8HHQ> — GDI Pressure sensor testing — 5:17

https://youtu.be/mHeGE3xa_Vs — GDI Exhaust Temp sensor — 3:22

<https://youtu.be/pTZDKciQ6HU> — GDI explanation — 2:44

<https://youtu.be/vyakvlo-i-68> — How to Seafoam your vehicle — 9:04

<https://youtu.be/f5faqSGWSlo> — How to Seafoam your vehicle — 5:24

<https://youtu.be/IISXReuvsE8> — Ford Ecoboost explanation — 1:31

<https://youtu.be/Nze7XKSzCEc> — Ford Ecoboost engine explanation — 15:22

<https://youtu.be/3t908YJRebw> — Ford Ecoboost 1.0L engine explanation — 5:19

<https://youtu.be/TTTgeV35g40> — Ford Ecoboost 1.0L engine explanation — 9:38

<https://www.youtube.com/watch?v=LjJSbHxIvnM> BOSCH — Video System Overview — 8:26

<https://www.youtube.com/watch?v=Pxxvp9F-PS34> — Video Hyundai Theta Engine — 2:41

<https://www.youtube.com/watch?v=KIVdPaTSot8> — Video Lubrizol Introductory of system — 2:47

<http://auto.howstuffworks.com/direct-injection-engine.htm> — HowStuffWorks article on GDI

<https://www.youtube.com/watch?v=H6p0sVdMeeQ> — Video PFI vs GDI ADP Training — 3:38

<https://www.youtube.com/watch?v=hHmM4hO9IP8> — Hyundai's V6 GDI Engine — 3:08

<https://www.youtube.com/watch?v=Ep-CEKzEhMU> — Ford 3-cyl Ecoboost — 3:06

<https://www.youtube.com/watch?v=IzXeeCiSL7k> — GDI system failures — 3:52

https://www.youtube.com/watch?v=uIGe_kBhHNC — Learn Burn Stratified (use) — 2:46

<http://www.roadandtrack.com/motorhead-university/sponsored-content-gasoline-direct-injection-101> — Road & Track Basic article

http://www.hotrod.com/techarticles/engine/hrdp_0909_direct_injection_guide/ — Hot Rod article on basics

<https://www.youtube.com/watch?v=hybKYFUOs3Q> — Video Basic and advanced overview — 5:49

<https://www.youtube.com/watch?v=hNtsx78ZTBs> — Video GDI on Nissan JUKE — 3:21

<https://www.youtube.com/watch?v=4FG8tSWrCI8> — Video GDI Injector operation by ADP — 4:29

<https://www.youtube.com/watch?v=4M9BITr1zhg&list=PL77A6348FB611F4F&index=6> — GDI HP Pump operation by ADP — 4:28

<https://www.youtube.com/watch?v=0oE9JCmsxeg> — Video Ecotec GDI operation & diagnosis by Autolite — 14:04

<https://www.youtube.com/watch?v=Rh6SxwTc2g&list=PL57B331239D8F5F0D&index=14> — Video Hyundai 1/6 GDI — 3:23

<https://www.youtube.com/watch?v=5BUpekjAWH8> — Video Ferrari V12 GDI engine — 3:14

<https://www.youtube.com/watch?v=qd90yHlmsS4> — Video GM GDI technology — 1:44

<https://www.youtube.com/watch?v=XIXwMTbL26Y> — Video GDI injector animation — 0:54

GASOLINE DIRECT INJECTION

GDI VIDEO LINKS

<https://www.youtube.com/watch?v=YzIIoP2dz8E> — Video Audi GDI animation — 0:32
<https://www.youtube.com/watch?v=cgwyQtU4MW4> — Video Ford V6 GDI animation — 0:37
<https://www.youtube.com/watch?v=wmHxiY2J8Ok> — Video Ford Ecoboost GDI — 2:40
<https://www.youtube.com/watch?v=IFj5UIZx2cE> — Video Ford 1.0L GDI engine — 2:59
<https://www.youtube.com/watch?v=3t908YJRebw> — Video Ford Focus 1.0L detailed explanation — 5:19
<https://www.youtube.com/watch?v=rJ9ui0guXzA> — Video GM's HCCI engine animation — 1:40
<https://www.youtube.com/watch?v=OXd1PIGur8M> — Video Ford PFI engine assembly animation — 5:43
<https://www.youtube.com/watch?v=OXd1PIGur8M> — Video 2-cycle GDI — 1:27
<https://www.youtube.com/watch?v=zc8aUxBZlsU> — Video Scion/Toyota D-4S boxer GDI engine explanation — 2:15
http://www.roadandtrack.com/go/out-of-turn-toyota-engine?src=soc_fcbks — Road & Track Toyota's piston-less engine

WIDE BAND OXYGEN SENSORS:

<https://www.youtube.com/watch?v=r1opwkhKDs> — Video – Wide-Band O2 sensor operation (performance) — 3:03
https://www.youtube.com/watch?v=zjefDrFH_6c — AutoMate video – Basic operation — 6:27
<https://www.youtube.com/watch?v=XQYDwIWS6Ho> — Basic operation Part 1 — 29:59
<https://www.youtube.com/watch?v=K8GLH6ubXoc> — Basic operation Part 2 — 22:42
<https://www.youtube.com/watch?v=7Xm2rYOXT8s> — How to test a wide-band Pt 1 Scanner Danner — 26:17
<https://www.youtube.com/watch?v=s7zv9uzs0b4> — How to test a wide-band Pt 2 Scanner Danner — 26:17
<https://www.youtube.com/watch?v=gZZDIuZ476s> — How to install a Holley aftermarket wide-band sensor — 8:57
<https://www.youtube.com/watch?v=RKNUZUTKguk> — ADP Training Basic AFR or Wide-Band operation — 2:48
<https://www.youtube.com/watch?v=IQQyzHYfqws> — Narrow Band vs Wide-Band comparison (motorcycles) — 2:52
<https://www.youtube.com/watch?v=xTRKGP9N1PY> — How PLX aftermarket wide-band sensors work — 3:02
https://www.youtube.com/watch?v=DMFF_QfEdgs — ADP Wide-band sensor circuit — 1:44
https://www.youtube.com/watch?v=hV98qgw_4tU — Basic operation – Bobby Sturgeon — 2:51
https://www.youtube.com/watch?v=_QwT81RuGWw&list=PLLOYjXbrBW-YQhNhB9KeVqvtI8CjEPA_4 — Aftermarket — 7:56
<https://www.youtube.com/watch?v=Kr-c8eBI5E> — Toyota wide-band DTC P1155 & replacement Chris Fix — 4:45
https://www.youtube.com/watch?v=G_89r12vZFw — Fuel Trim used for mis-fire type of cause Scanner Danner — 12:19

ELECTRONIC THROTTLE CONTROL (ETC):

<https://www.youtube.com/watch?v=KXSBjLgNx4E> — Video Electronic Throttle Body (Tech Sessions) — 4:29
<https://www.youtube.com/watch?v=EDpUo3UPmto> — Video Ford Electronic Throttle Body failures — 3:26
<https://www.youtube.com/watch?v=Yg1DiZEBod0> — Video GM ETC cleaning and repair — 14:02
<https://www.youtube.com/watch?v=Pgl9L5Y7sQ> — Video Electronic Throttle Control explanation — 2:30
<https://www.youtube.com/watch?v=IPNnHU6PYbo> — Video Cleaning ETC throttle Body — 4:35
<https://www.youtube.com/watch?v=XrcaDh4xDLs> — Video Cleaning ETC throttle bodies (Rock Auto) — 3:30
<https://www.youtube.com/watch?v=jKR6oqKPO1Q&list=PLrdmR5y7THrpanR1fYecahOA2Xhe4okf> (This link will take you to the first of over 200 videos on ETC – Other links appear on right-hand column of video being played.)
<https://www.youtube.com/watch?v=6bvH9Sv7GkQ> — Toyota Explanation — 3:48
https://www.youtube.com/watch?v=oHJLZ_0ncXw — Snap-on Testing ETC systems — 3:29
<https://www.youtube.com/watch?v=Pgl9L5Y7sQ> — Basic system explanation — 2:30
<https://www.youtube.com/watch?v=GtT414fPbgY> — Basic explanation Part 1 Standard Products — 3:39
<https://www.youtube.com/watch?v=jKR6oqKPO1Q> — Basic explanation Part 2 Standard Products — 3:41
<https://www.youtube.com/watch?v=IPNnHU6PYbo&list=PLrdmR5y7THrpanR1fYecahOA2Xhe4okf>
— Cleaning ETC throttle bodies – FordTechMakuloco — 4:35
<https://www.youtube.com/watch?v=ZNxXM75zIOW> — Ford Vehicles: Electronic Throttle Body Relearn Procedure — 6:57



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