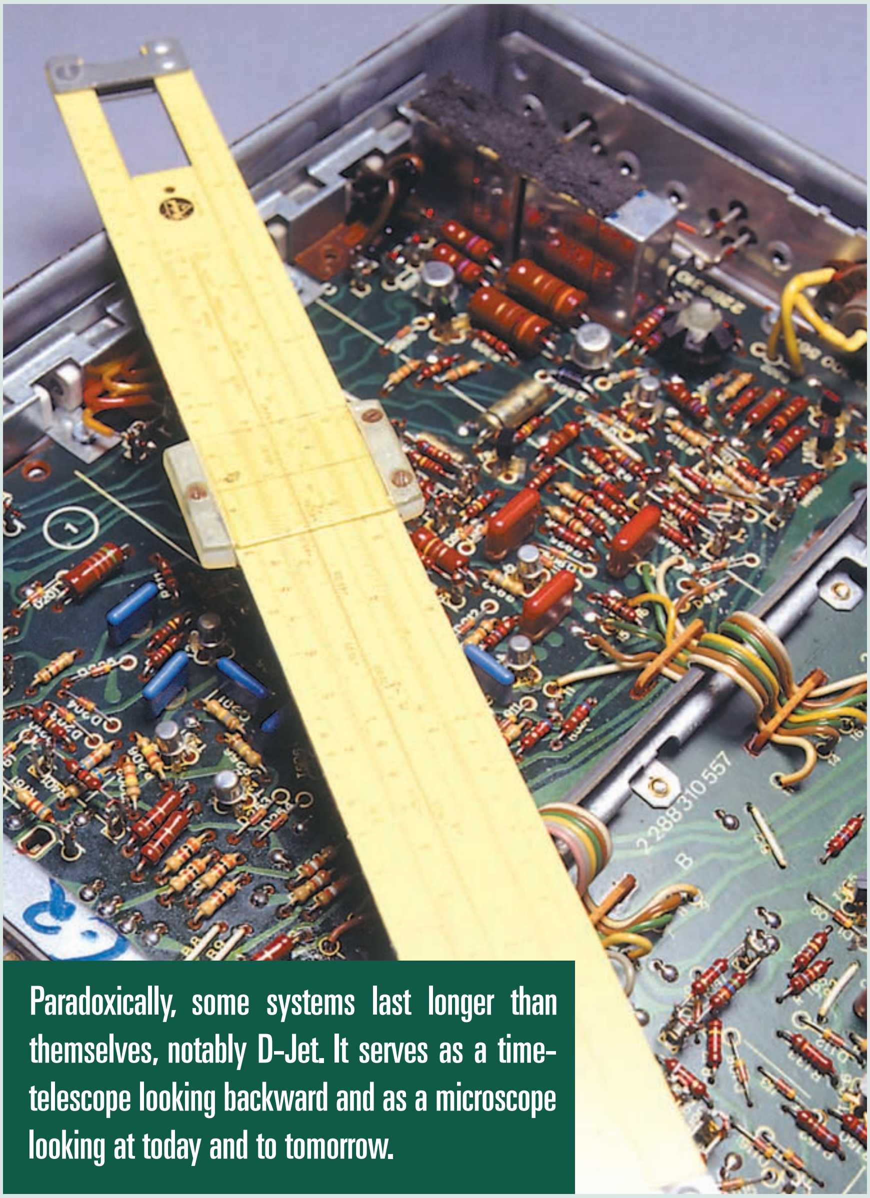
D-Jet Rules!

The Mother of All (well, the mother of most) Fuel-Injection



Paradoxically, some systems last longer than themselves, notably D-Jet. It serves as a time-telescope looking backward and as a microscope looking at today and to tomorrow.

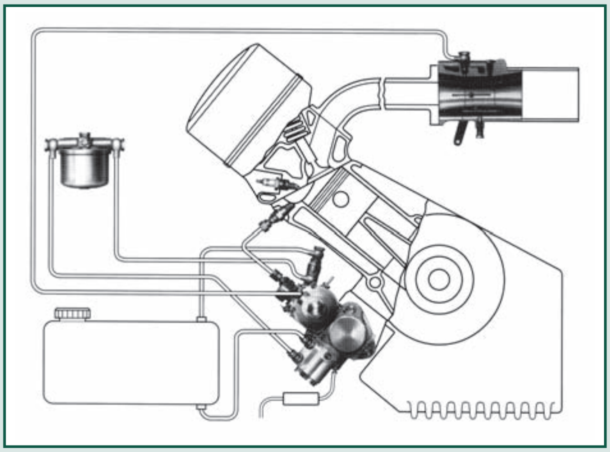
Fuel injection for automotive engines goes back at least to the folks at Gasmotorenfabrik Deutz in 1898, whose mechanical plunger-pumps fueled turn-of-that-century engines until those goldurned newfangled contraptions, carburetors[!], supplanted them. Almost since then — since 1912, that is — Robert Bosch GmbH of Stuttgart has built automotive fuel injection, and also Diesel, racing and aviation systems. From the beginning, the most difficult design problem for gasoline injection was inventing a method to correctly proportion and mix the fuel with the air entering the engine, across all combinations of load, speed and temperature, a problem still not perfectly solved by combustion engineers.

'Gullwing' Direct Injection

The 'Gullwing' Benz SL 300 from the early 1950's had perhaps the first Bosch gasoline-injections systems widely seen in North America. This system was purely mechanical and sprayed fuel directly into the combustion chamber, very like inline-rack Diesel injection systems from Bosch and others, and for that matter very like the latest direct gasoline injection systems at the business end of the injectors. Daimler-Benz used similar systems on several less celebrated cars as well.

Details of the system are a bit sketchy now, but only the mechanical injection pump itself, evidently driven at camshaft speed by the timing chain, and a vacuum device, presumably varying delivery volume by load, appear on schematic diagrams. Though radically simple by today's standards, the system provided good enough air/fuel mixture control for its six-cylinder inline engine to punch the Gullwing along the road at speeds over 160 mph. Almost fifty years later, few modern cars can do that.

Good thing, too, probably. Even for the German domestic market, inured to high-speed Autobahns and equipped with the world's best suspensions and brakes, both Daimler-Benz and BMW cap their vehicle speeds at 155-mph



The purely mechanical fuel injection system on the Gullwing 300 SL resembled inline Diesel injection pump systems, but there was a vacuum connection to the intake manifold to reflect load. Notice this system, like the latest today, injected the fuel directly into the combustion chambers.

(250-kph). Try to go faster, and the computer snatches away your fuel pump ground circuit. Try anything close in North America, and you're likely to find out how to make big rocks into little ones with a heavy hammer in the hot, hot sun.

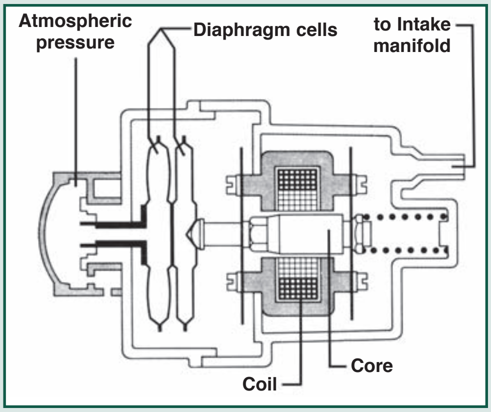
The Gullwing Benz was very famous, but even around the factory where they built it, its numbers hardly choked the streets. Unless yours is a very unusual shop, you can expect to see about as many Armstrong-Siddeleys, Stutz Bearcats or ZIL's as SL 300 Gullwings in your workbays.

The first fuel-injected cars in real-world visible quantity started with the Bosch D-Jet system in 1967, used for about ten years on many German and Swedish cars, from Benz to VeeDub'. But this system has much more to it than mere historical and car-buff interest. We'd not ordinarily use pages of *Import Service* to go into technical detail on a thirty-three-year-old system you're unlikely to see again, but D-Jet is different. D-Jet is to fuel injection almost as contact point distributors are to spark ignition: the technical/conceptual basis for many of the later developments. Today's speed-density systems are the direct descendants of D-Jet, and it's quite likely to survive in those modern reincarnations for many years. More to our point here, if you understand the comparatively simple D-Jet, you can understand the more complicated speed-density, which we'll get to next. So, gentlefolk of the wrench, let's have at it!

D-Jet – Juggling Pressures

"D" is for the German word, *Druck* (say *drrrook*, and r-r-roll your *Arrr*), meaning pressure. The fuel injectors spray fuel by hydraulic pressure from an electric pump, of course, but essentially the system works by carefully monitoring the difference in pressure between the intake manifold and the barometric ambient, along with inputs from a very few other sensors. There's no 'swinging-door' airflow sensor as on L-Jet; there's no hotwire or hot-film sensor as on mass airflow systems. We'll talk about the computer in a moment. The only sensors are the manifold pressure sensor, the air temperature sensor (and on some cars the coolant temperature sensor), the throttle position sensor and the injection trigger contacts in the base of the distributor. That's the whole D-Jet system!

D-Jet derives closely from (and was licensed through) a Bendix fuel injection system found on a *very* few domestic and race cars several years previously but never effectively utilized by domestic carmakers. Who knows why? Some retired Detroit beancounter is probably still explaining that scintillating brilliance.



The critical part, the pivotal component of the D-Jet system, was the manifold pressure sensor. Notice this is not a modern manifold absolute pressure (MAP) sensor, but a device to monitor the approximate (see text) pressure differential between the intake manifold and the ambient barometric pressure. The signal from this sensor was the most important input to the D-Jet system.

Unlike almost all other fuel injection systems we have or will consider in this series, D-Jet was not part of an oxygen-sensor feedback system to optimize emissions chemistry. While some emissions laws were in effect since 1963 (when PCV systems became mandatory), D-Jet focused on improving driveability and performance over what carburetors could deliver.

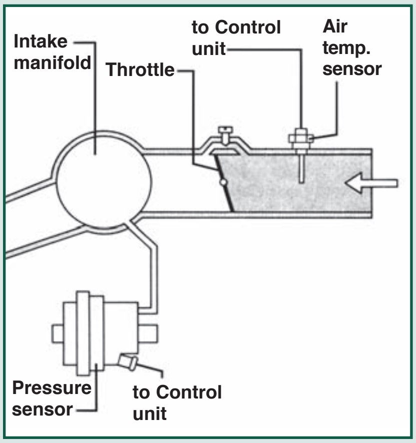
For practical purposes, these are its major advantages: It solved the carburetor's problem of uneven fuel distribution among cylinders (up to 60 percent mixture difference by cylinder!) with its individual injectors in each intake runner; it solved the problem of acceleration enrichment by electronic calculation of the injector pulsewidth rather than squirt-gun spurts down the venturi; and (on some systems) it could shut off fuel entirely when decœlerating, preventing backfire and cylinder wall lube oil washdown. Built in an era when you could engineer for performance, not for emissions, it turned out to improve both.

The system was unique in several respects: The D-Jet had an analog (*not* digital) computer: It's a slide-rule, (remember them?), not a calculator. While relatively large in those days before micro-miniaturization, it was hardly as complicated as a pocket radio or calculator. Analog computers are almost unknown now, so they bear some explanation. They contrast with digital computers, the kind we're now used to. Digital computers in modern cars work by on-off signals or by numbers, base-two numbers — which are also on-off signals, but at very high speeds. The digital advantages are incredible speed and precision. The D-Jet's analog computer, however, works with voltage gradients, not with base-two numbers. You'll see no chips on its board, just caps, resistors, diodes and transistors. While much slower than a digital computer, it is also much simpler, so it can still keep ahead of the engine (actually, a contact-point ignition distributor, with vacuum and centrifugal advances, is a kind of *very* slow mechanical computer — like an antique Chinese abacus compared to a calculator – but still fast enough to keep up with its engine). Analog worked for the original D-Jet; it doesn't work anymore.

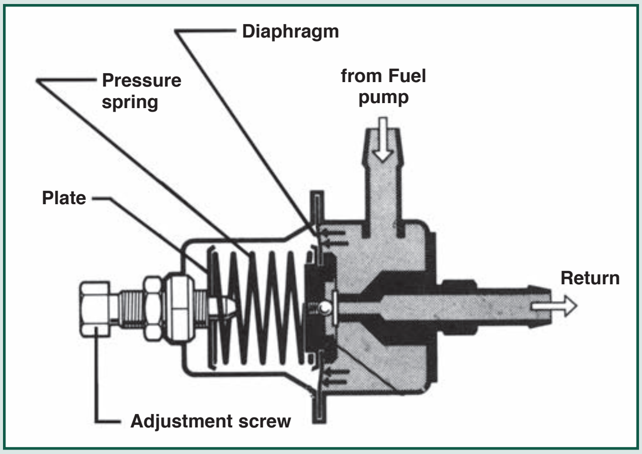
The Manifold Pressure Sensor

Don't accidentally read an extra word into that description: This is not a manifold *absolute* pressure sensor! This sensor is key to the D-Jet system, as its successors are to the speed-density systems we'll consider later. There are two fixed aneroids in mechanical series, in tandem: one vents to the outside ambient air; the other is filled with a reference gas, presumably some sort of rarified Alpine air functioning as a standard. The rest of the sensor opens to the intake manifold pressure (partial vacuum). As the manifold pressure changes, the aneroids move the iron core in the center of the sensor's coil. This changes the coil's inductance, the resistance to current flow a coil builds in itself with the generated magnetic field; and this reflects the intake manifold pressure in a finely discriminated way. This signal becomes the dominant factor in the computer's calculation of injector pulsewidth. Notice that by including two aneroids in tandem, the system gets a signal that is an average between a true manifold absolute pressure signal and an altitude/barometer-corrected pressure differential signal. Not perfect, but close enough for standards of the time.

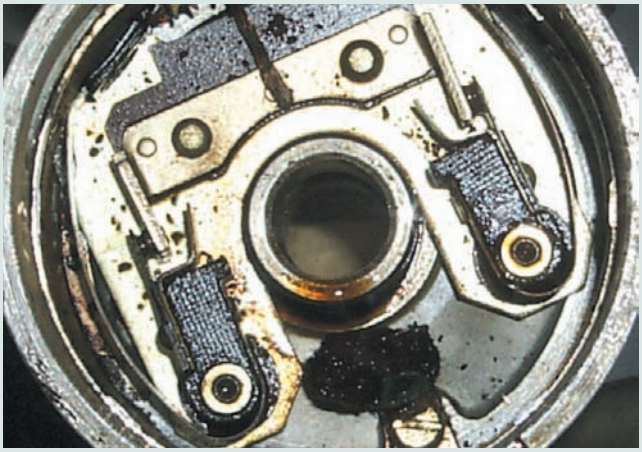
If the throttle opens by a certain amount, the throttle position signal voltage changes by a corresponding voltage. Ditto for the air temperature sensor, though back in '67 people just wanted to distinguish winter from summer. Then the D-Jet analog computer increases injector pulse-width by another corresponding amount, factoring in all the other elements relevant to that calculation, like coolant temperature, air temperature and the difference in pressure between the intake manifold and the ambient air. All these signals work on sliding scales like the elements of a slide-rule to yield a duration signal, the injectors' on-time for that set of sensor readings.



The air temperature sensor, a much less sensitive thermometer than on modern systems, is in the intake airstream ahead of the throttle. Some D-Jet systems use a similar temperature sensor for the coolant.

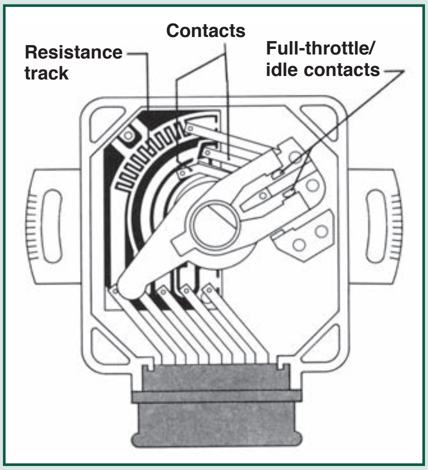


The D-Jet fuel pressure regulator, as explained in the text, held a constant 2 bar, regardless of altitude, temperature, barometric pressure, throttle position or engine load. This was a favorite place for DIY-ers to tinker, 'raising the pressure for more power.' Changing the pressure, however, richened the mixture at some combinations of speed and temperature and leaned it at others. Once you got the pressure right, this was a good candidate for paint on the threads.



Under the ignition parts of the distributor were the contact points to trigger fuel injection. With far lower current than an ignition primary, injector trigger points tended to last for the life of the car unless the distributor bushings went away.

Fuel pressure was not only constant but manually adjustable. Perhaps *manually maladjustable* would be a better description, since while varying the pressure did change the mixture, it changed it different amounts at different points on the load/temperature/speed continuum. You've doubtless seen multi-dimensional ignition and mixture maps, vaguely reminiscent of topological maps of a mountainous landscape. Changing the pressure on the D-Jet's regulator was like shifting the mixture-map sideways, so only the rarest of graphpoints coincide with the correct settings, most graphpoints will fall too rich or too lean. Playing with a pressure the computer assumes constant can't have good effects.



The D-Jet throttle position sensor, with a wide range of adjustment and misadjustment via the serrated mounting slots, included idle and WOT switches. It also includes a sliding contact path for acceleration enrichment, a function generally calculated by the computer from the speed of throttle position movement in later systems. D-Jet used both increases in pulse-width and supplementary fuel injection pulses to enrich mixture.

The amount of fuel injected on such a system depends entirely on the pressure differential between the fuel and the intake manifold and the time the injector valve is open, and the software expects a constant fuel pressure. But the computer also expects to find 'factory-standard' flow conditions, so there were infinitely many possible adjustments, only one of them right. And not even one if there were restrictions on fuel flow anywhere from the pickup sock to the final mesh screens in the injectors. On most D-Jet applications, delivery pressure was a mere 2 bar (29 psi.).

This differs, obviously, from modern developments of the D-Jet system. The higher the pressure and the smaller the holes in the injector nozzle you blow the fuel through, the finer will be the fuel stream and its gas-mist droplets. The smaller these are, the more thoroughly the fuel can vaporize in the inrushing path of air, allowing a more complete combustion, saving fuel and keeping the exhaust clean (setting aside the question of NO_x).

There was, in this early system, no feedback signal, not from oxygen sensors, not from knock sensors, not from anything else. There was no catalytic converter to blow the exhaust of a stoichiometric mixture through. Neither the complications nor the effectiveness of most computer controls had yet occurred.

In later articles, we'll look at where the D-Jet leads, to pressure-based systems that can achieve exhaust emissions quality and vehicle fuel economy demanded by current laws. Some systems are close enough to right the first time to stay around in one form or another for a long time. ■

—By Joe Woods