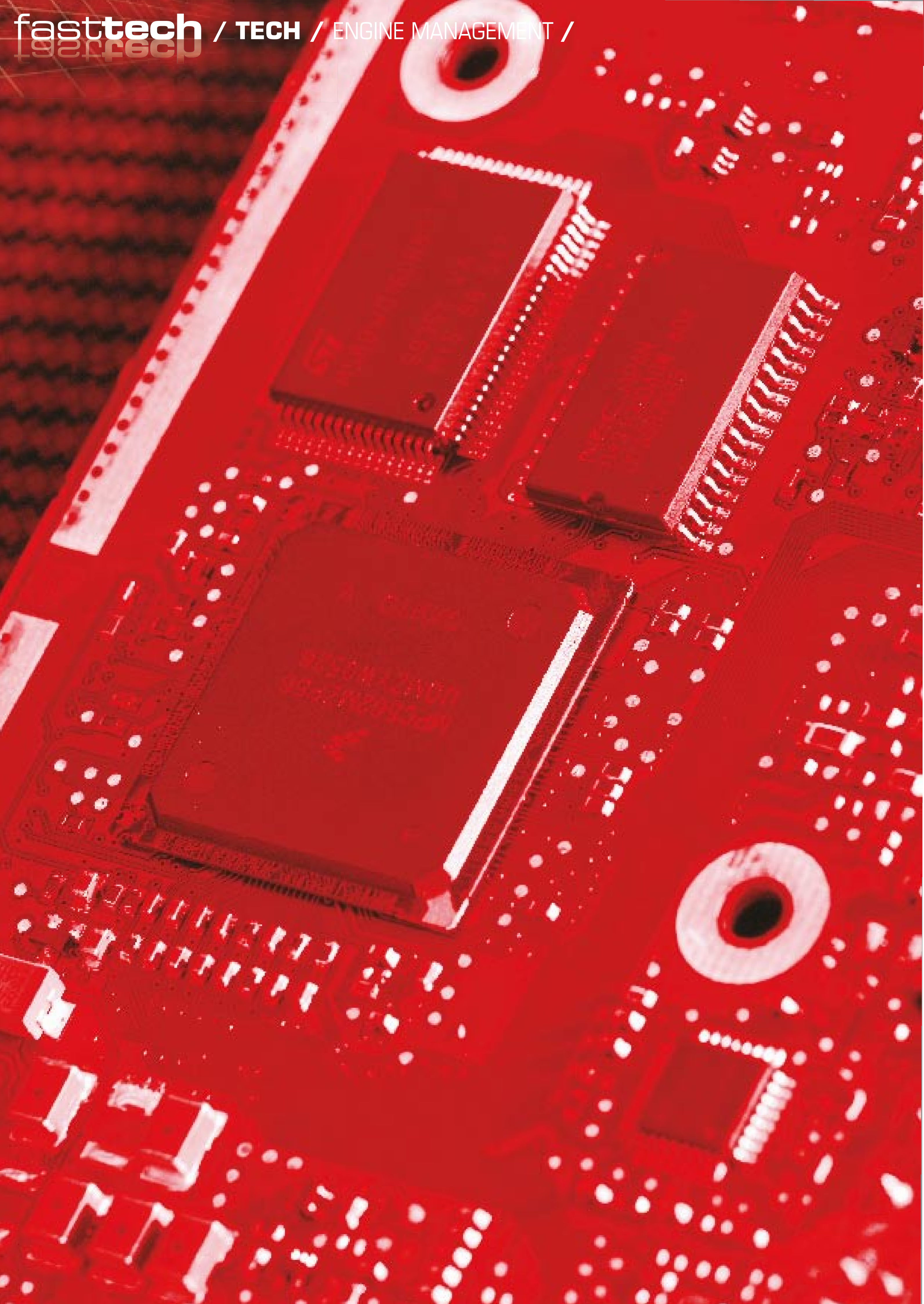


CIRCUIT TRAINING

Words: Stewart Sanderson

Engine management systems (even '80s Ford ones) are much more involved than you might think. Here's what you need to know.

Modern ECUs constantly monitor what the engine is doing, including revs, air and coolant temperatures and air/fuel ratio

LAST month, we looked at the majority of sensors to be found within a modern car's engine bay. The multitude of those we discussed are fitted to the engine with the sole purpose of feeding information back to the engine management system, so that it has all the information it needs to perform its vital tasks. This month, we're going to look at what the most important tasks performed by the management computer really are and how it actually performs them after utilising all the information provided to it by the input sensors.

As briefly mentioned last month, there are two different systems commonly in use on your Ford: the Speed Density system (Weber Cosworths and Fiesta Turbos), and the Mass Air Flow system (pretty much all the rest!). Let's start with the old speed density systems because these are the most basic of all but use virtually all the same sensors as the Mass Air Flow system bar one main one.

SPEED DENSITY

Speed density takes its name from the fact that it calculates the amount of fuel to inject into an engine's cylinder by using both engine speed and air density as the two main factors. Engine speed is quite simple to measure and calculate, because it uses the speed signal coming from the crankshaft speed sensor. But air density? How does it work that out?

Well, it uses the output from the MAP sensor to tell it what the manifold absolute pressure is at any given time, and it also uses the output from the air temperature sensor to keep it fully up to speed with the temperature of the air in the plenum chamber. That means it knows both the pressure and temperature of the air about to enter the cylinders.

Using these two pieces of information, it can calculate the actual density of the air very accurately indeed. The air density relates to the amount of oxygen likely to be present within the plenum at that particular instance, and thus has a bearing on the engine's fuel and spark advance requirements.

Speed density systems are very fast, very accurate, and because they measure the characteristics of the intake charge actually inside the inlet manifold, they give good, reliable and repeatable results. However, they still suffer from one very serious flaw. The actual temperature and, more importantly, the actual pressure, of the intake charge in the combustion chamber is never going to be exactly the same as it is in the inlet manifold.

The air charge must pass from the plenum, where it's measured, through an inlet tract in the cylinder head and then past an inlet valve or two before it even reaches the combustion chamber. Along this journey it will also be subject to resonances and other complex factors that can both reduce or increase (but mostly reduce) the actual amount of air that ever makes it into the cylinder itself on each intake stroke. In order to be able to account for these differences in air flow, a speed density-based ECU also needs one further piece of vital information before it can accurately perform its

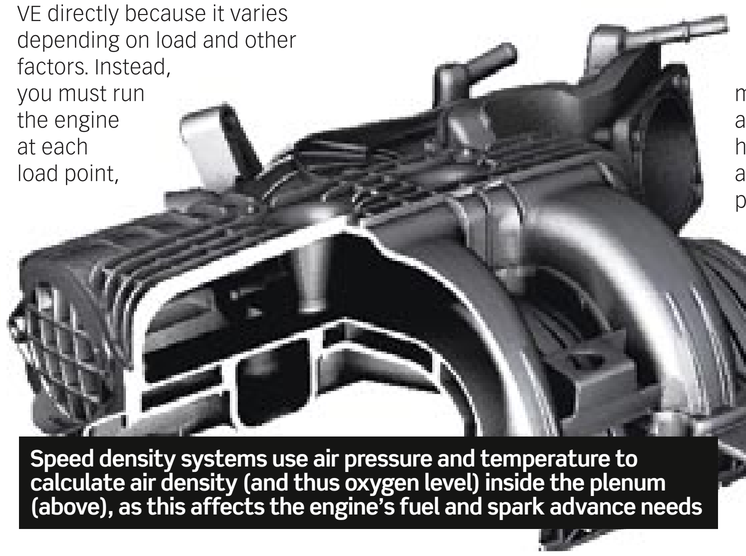
On speed density-managed cars, altering the breathing capabilities means your ECU will require a remap

calculations – something known as a volumetric efficiency map. This is simply a reference that enables the ECU to calculate how much of that dense air will flow into the cylinders themselves with any given throttle input at any given engine speed. Essentially, it's a map that relates to how efficient the engine itself actually is.

However, the problems associated with using a volumetric efficiency map are twofold. Firstly, there's no sensor you can use to measure VE directly because it varies depending on load and other factors. Instead, you must run the engine at each load point, and then manually adjust it until you get the air-to-fuel ratio perfect using exhaust gas and temperature sensors.

Secondly, every time you do anything at all to the engine that changes its breathing ability, you instantly change the VE across the range. Therefore, you must once again recalculate all the VE points if the management is to do its job correctly. As the engine ages, it accumulates carbon deposits on the pistons that increase the compression ratio, the cam lobes wear so the cams open a little less, and so on and so forth. This means that the volumetric efficiency of the engine is constantly changing, and the state of tune is constantly deteriorating as a direct result. From an emissions point of view, this really is very poor indeed.

So remember folks, if you do something to make your speed density-managed system flow air differently to standard, or even to when you last had your new performance chip written, expect problems with it sooner rather than later. The ECU is totally blind to your meddling and has *not* added the extra fuel you should now need to stop the engine melting down like a Mars bar in a furnace. Adding turbos, cams, headwork, bigger throttle bodies, anything like that at all, will 100 per cent require a remap if you want to avoid disaster. So beware out there, please...



Speed density systems use air pressure and temperature to calculate air density (and thus oxygen level) inside the plenum (above), as this affects the engine's fuel and spark advance needs

MASS AIR FLOW SYSTEMS

Considering all the above, wouldn't it be nice if we could have a management system that had all the power of the speed density unit, but which could actually compensate for any changes in volumetric efficiency (VE) all by itself? A system that could see the air density and, more importantly, the actual air flow, and automatically adjust the fuel delivered for it? You've probably already guessed by the name that this is exactly what a mass air flow system does – it measures air flow as well as density.

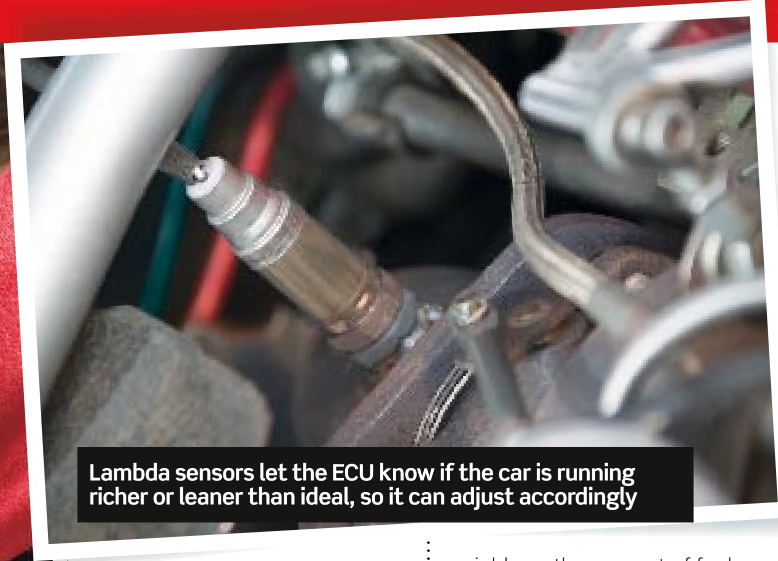
Apart from this, the rest of the system works much the same as a speed density one, and simply monitors the engine sensors, makes decisions about what to do with ignition, idle and fuelling, and then sends out the relevant signals to get the job done. But what jobs are we talking about exactly? Let's take a look at the main hardware activation and control circuits, and then we can look at the various operating modes and features.

FUEL INJECTOR OPERATION

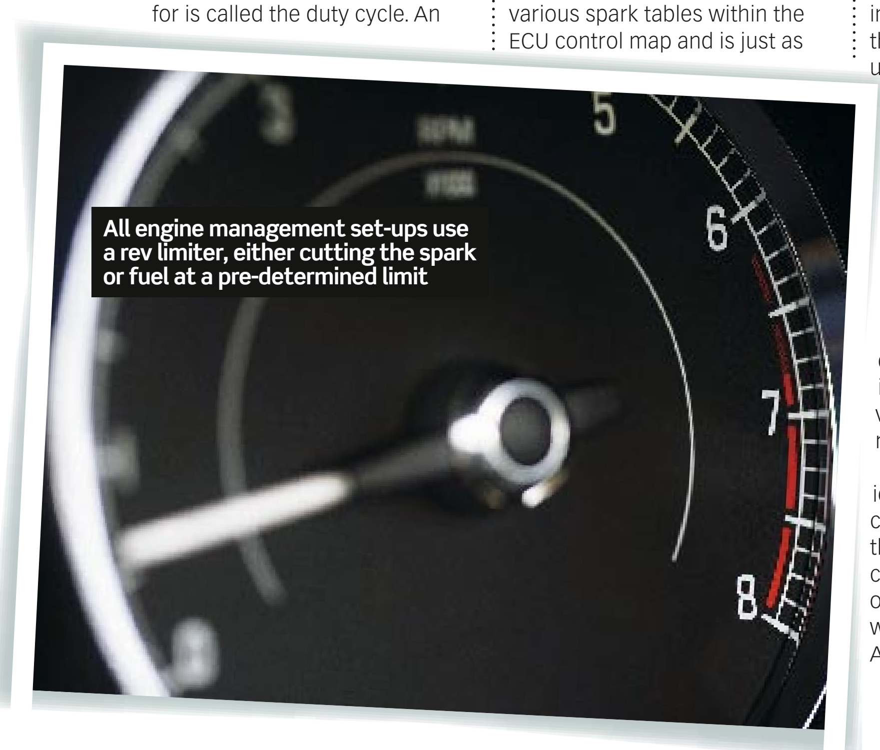
Arguably the most important components that the ECU control are the fuel injectors. The amount of fuel that flows through the injectors is determined by the length of time that the ECU switches them on for. When they're switched on, fuel squirts out of them in a fine spray. The pulsing on and off of the injectors is the clicking noise that you can hear if you listen really closely to a fuel-injected engine.

The time that they're switched on and open for is called their pulse width. The percentage of time that the injectors are open for is called the duty cycle. An injector open for half the time has a 50 per cent duty cycle, while if it's open for three-quarters of the available time, it has a 75 per cent duty cycle. At maximum power in a standard engine, the injectors might have an 85 per cent duty cycle. That means the injectors are flowing at 85 per cent of their full capacity.

A good-quality multimeter can be used to read off the injector duty cycle by back-probing the injector plug when it's connected to the injector. It's worth noting that it's not recommended to exceed 85 per cent duration for reliability reasons.



Lambda sensors let the ECU know if the car is running richer or leaner than ideal, so it can adjust accordingly



All engine management set-ups use a rev limiter, either cutting the spark or fuel at a pre-determined limit

SPARK PLUG FIRING

In most systems, the ECU does not normally control the ignition coil (or coils) directly. Instead, an ignition module is used to switch the power to the coil on and off, with the ECU actually telling the ignition module exactly when it needs to do this switching so that the spark is delivered at just the right time.

Spark time is taken from various spark tables within the ECU control map and is just as variable as the amount of fuel to be injected. If you missed it, it may be worth reading our in-depth feature on spark advance in issue 244/September 2006 for more details.

IDLE SPEED CONTROL

Idle speed control is carried out by changing the amount of air that can bypass the closed throttle butterfly. In all cases, we have a throttle plate bypass channel installed. It's essentially blocked by the idle valve, so when it's closed we have no air bypassed, and when it's open we have lots of air bypassed, and hence a very high idle speed.

Some cars use a pulsed valve (a bit like an injector in the way it switches on and off) to regulate the amount of air that can get past the throttle body. If the idle speed needs to be raised, the duty cycle of the valve is increased and more air squeezes through. Often, the valve is only used to its full potential when the engine's cold, because they have an increased idle speed requirement when temperatures are lower. In these scenarios the duty cycle to the valve is high when the engine's cold and gradually decreases as the engine warms up until, when the engine is fully warm, very little (or none, depending on the system) air is allowed to pass through the valve, and so the idle speed remains low.

Other times at which idle speed compensation is commonly required are when there's high electrical load – it compensates for the large draw of power from the alternator, which will slow the engine slightly. Air conditioning compressors also affect idle speed, as these add a huge rotational load, and sometimes the engine speed is kept falsely high on overrun until a vehicle is stationary, because this reduces emissions.

Fuel injectors are the most important component that the ECU controls

OTHER THINGS?

There are a whole host of other things that can be operated by the ECU. The radiator fan is a common item switched on and off by the ECU, and in turbo cars the boost level is usually fully ECU-controlled. Automatic transmission control is often integrated into the engine management system too, not to mention seat, environment and headlight controls in many systems. Virtually all fuel-injected cars have the fuel pump activation done by the ECU through a relay, not to mention the management light and auto diagnostics that are an important part of the modern-day ECU. The diagnostic systems not only indicates to us humans when there's an engine management problem, but can also be used to communicate to us what the problem is actually likely to be.

STRATEGIES

The ECU has various strategies built into it for performing various modes of operation, such as idling, cruising, accelerating and decelerating, to name just a few. Let's take a quick look at how these can be expected to work.

CLOSED LOOP

Regulars will know that this is a favourite of ours, and Motorsport Developments went to the trouble of developing a system for Cosworths, so they can run closed loop perfectly even on very large injectors. The system works quite simply on paper. The ECU is programmed to keep the air/fuel ratio close to 14.7:1 – this is the mixture at which the engine gives the most power for the least fuel and producing the least amount of exhaust byproducts.

The oxygen sensor (or Lambda sensor, as it's often known) sends a voltage signal back to the ECU, telling it whether the car is running richer or leaner than 14.7:1. If the engine's running a little rich, the ECU will lean it out. If it's a bit lean, the ECU will richen it up.

The oxygen sensor constantly feeds back the relevant AFR as a rich/lean signal and the ECU makes adjustments to keep it perfect – hence the name 'Closed Loop'. Closed loop running on most cars occurs when the engine's up to operating temperature, the throttle opening is neither large nor small, and is operating within a predetermined engine speed range.

The ECU can, of course, switch back out of closed loop running instantaneously. You can be driving along gently in closed loop and then slam the throttle to the floor. The ECU instantly switches out of closed loop, ignoring the output of the oxygen sensor and substantially richening mixtures to a safer and more power productive level. None of this can be felt by the driver.

Closed loop running relies on the oxygen sensor being in good condition. If it's defective, the car won't go into closed loop, and both fuel economy and emissions will suffer.

REV LIMITING

All engine management systems use a rev limiter. Some of these completely cut off fuel at the prescribed engine speed, withholding it until you're 500 rpm below the limit. Hitting this type of rev limiter makes you think you've just broken something serious! Other rev limiters cut off the spark (or the injectors) of individual cylinders one after the other, so that you can barely feel that you've reached the maximum allowable revs. These soft-cut limiters mean that the car can be used right to the rev limit without a worry. Some systems even have both in case you somehow manage to ignore the soft limiter.

OVERRUN FUEL SHUT-OFF

When you lift off the throttle totally (like when you're coming up to a set of traffic lights) the ECU switches off the injectors for economy and ultimate emissions. The injectors come back on again when engine revs drop to around 1500 rpm so as to ensure the engine can idle properly. Injector shut-off has obvious benefits to both fuel economy and emissions, and thus needs no further explanation. It's one of the ECU strategies that's most reliant on the input of the speed sensor.

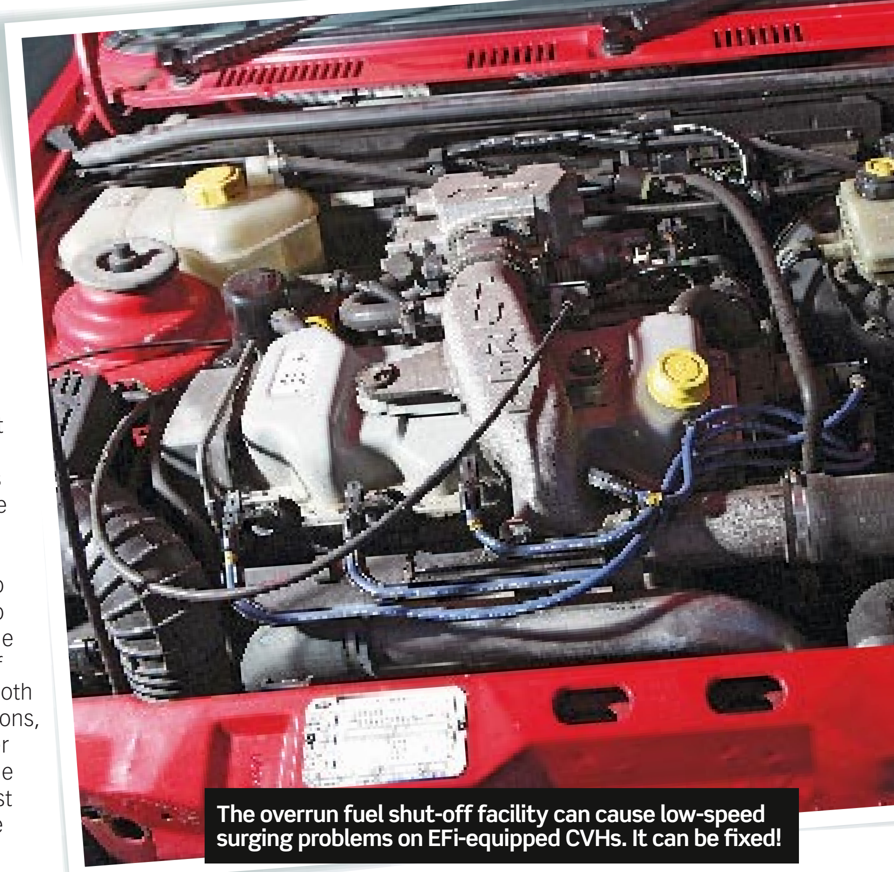
It's worth noting that sometimes these strategies can cause poor surging at low speeds when you're driving at light throttle. The CVH EFi was thus afflicted as standard, so often we remove the feature altogether in our maps if the car is affected.

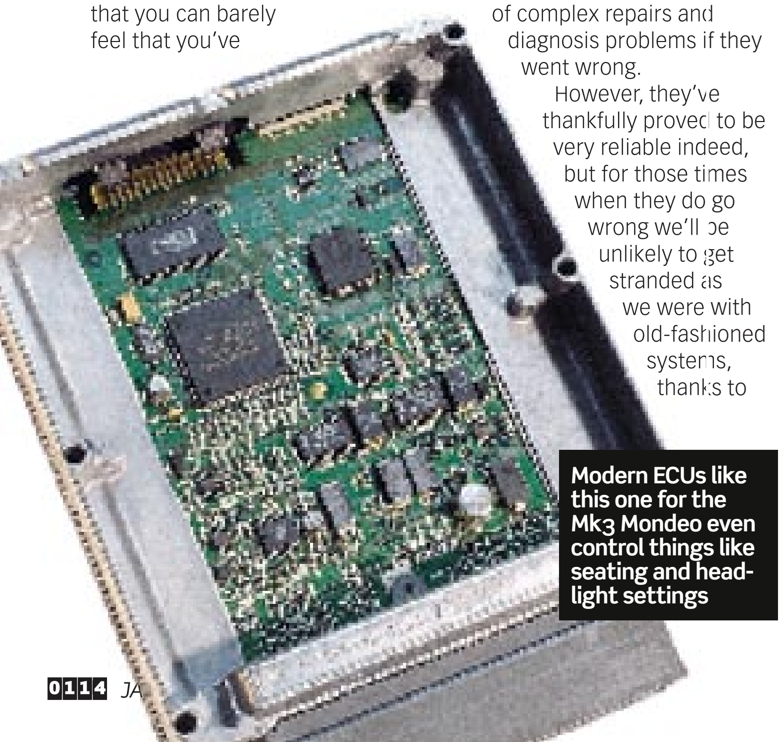
LIMITED OPERATION STRATEGY

When EFi cars were released, they were universally accepted as being the way forward for reliable fuel delivery, and incredible reliability was expected. However, as the system grew more complex, so did the possibilities of complex repairs and diagnosis problems if they went wrong.

However, they've thankfully proved to be very reliable indeed, but for those times when they do go wrong we'll be unlikely to get stranded as we were with old-fashioned systems, thanks to another wonder of the modern engine management system – the LOS. LOS stands for Limited Operation Strategy, or 'Limp-home mode' as it's become known.

Say a sensor was to fail – for example, the coolant temperature sensor becomes defective (or the wire to the sensor is damaged). The ECU sees that the sensor is down and substitutes a value based on the other sensor inputs instead. It is hoped that this will at least get you home. Some ECUs can do without all but a couple of inputs and still keep the engine running.


The overrun fuel shut-off facility can cause low-speed surging problems on EFi-equipped CVHs. It can be fixed!


Modern ECUs like this one for the Mk3 Mondeo even control things like seating and head-light settings

AUTO DIAGNOSTICS

All engine management systems of the past 10 years or so have what's called a 'self-diagnosis' ability. That means you can plug into them, ask them a question and they'll tell you what's wrong with them!

For example, imagine the intake air temperature sensor wire is broken. If you put the ECU into self-diagnosis mode (this often needs an expensive piece of equipment), the ECU will indicate that it's the air temp sensor that has the problem, so you can change it and ask the ECU to retest it, just to confirm your fault has gone.

It's worth noting, however, that they are *not* always right, and sometimes they can't see a fault that to the driver is blindingly obvious, but that's usually due to a sensor calibration failure, as opposed to a total electrical or mechanical failure.

That's enough for this month. Hopefully now you've got a good idea of what each sensor does and what jobs the ECU actually performs in its day-to-day engine-running tasks.

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NEXT MONTH

We'll look at how the ECU actually interprets the sensor inputs and comes up with the right fuel and spark requirements. We'll discuss how air, water, throttle and engine speed affect the spark and fuelling strategies. For example, what difference does the water sensor reporting 20 degrees make to the engine's fuelling when it's actually very hot and nearer 90 degrees? By the end of it, you'll see why sensor information is so critical. See you next month!