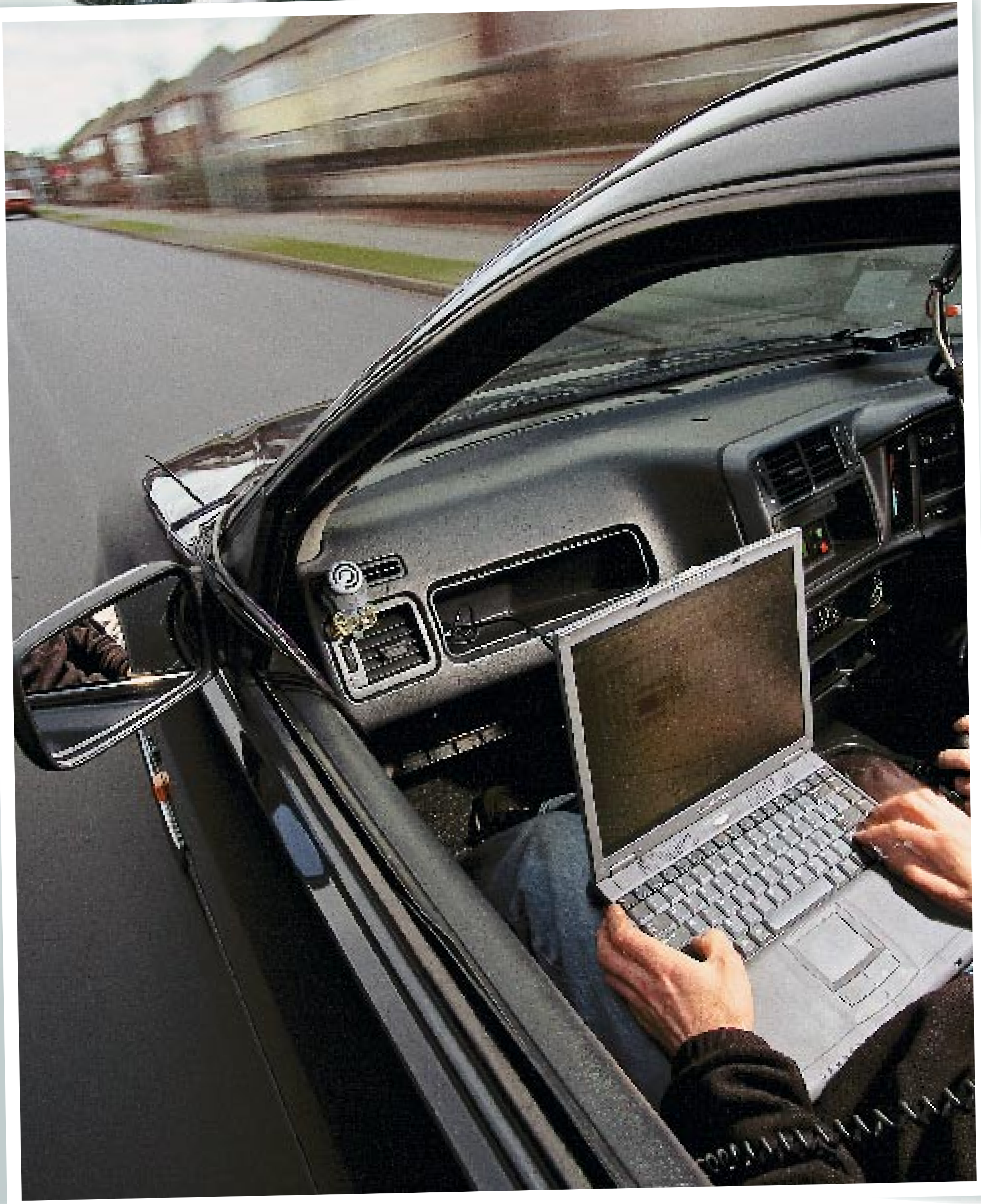
# OK COMPUTER

Know loads about engine management. Part one: how and what engine sensors are telling your ECU.

PART ONE



## ENGINE

management: two words that we hear everyday as enthusiasts, but what exactly does the term mean, what does it do for us and how does it do it?

Well, in a nutshell it does exactly as its name suggests, it manages the engine, but how it does so is a little more complex than may well meet the eye, so this month we will take a look at what role the engine's management sensors have in this complex management process.

It's worth noting that there are two fundamentally separate systems commonly in use today and those two systems are known as speed density and mass air flow. It's important to know this, as a couple of the sensors differ quite substantially between the two, as does the way the ECU calculates the fuel required. Read on to learn more...

## MANAGER'S SPECIAL

The first part of our engine management component list has to be the engine management computer, or the ECU as it is often called. This is simply a computer that is designed specifically to be able to process incoming information from its various different inputs, look for data on what to do at any given moment and then do as requested by controlling various different valves, solenoids, relays and so on.

We will see later on how this all works as first you have to understand the inputs available to feed it with information before you can hope to understand what processes it will go through to act upon that information.

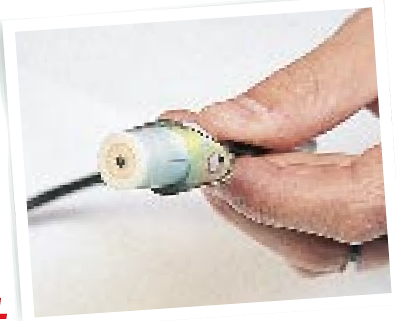
## SENSORS: SPEED DENSITY SYSTEM

As mentioned earlier, we have two different systems in use today, so let's examine one at a time.

Let's start with speed density and we can look at the extra sensors for mass airflow later on. These systems normally consist of the following common sensors:

**Engine speed sensor**
**Water temperature sensor**
**Air temperature sensor**
**Manifold Absolute Pressure sensor**
**Throttle position sensor**
**Phase sensor (if sequential injection)**
**Knock Sensor (better systems)**
**Lambda sensor (from around 1991)**

Let's now take a closer look at how these different sensors actually work and what the ECU uses the information for.



## CRANKSHAFT SPEED AND POSITION SENSOR (CPS)

These sensors vary in their operation from simple magnetic triggers to inductive Hall Effect units, but their principle is the same. They require markings on the crankshaft so they can monitor not only its speed but its position with relation to TDC.

A primitive one, like on an early Cosworth, uses four simple lugs on the crankshaft pulley. These lugs are 90 degrees apart situated at TDC, 90 degrees ATDC, BDC, and 90 degrees ABDC. This positioning on a four-cylinder engine represents top dead centre on each cylinder.

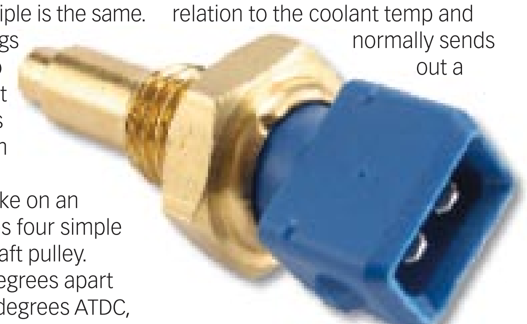
This information, due to the frequency it is actually sampled, is normally seen back at the ECU in the shape of a waveform. The waveform's accuracy depends quite heavily on the pulley being in good order and the gap between the pick-up and the lugs being within tolerance and all equal — as low speed signals will normally be so weak they can miss trigger events totally if something is wrong.

The ECU uses this engine speed information to deliver not only fuel but also spark advance. Most of the important tables within the ECU software are actually speed related so it's important your sensor is delivering the correct information at all times.

Errors with this sensor can cause anything from a haywire rev counter to a very hard-to-drive engine. Various strategies base their results on the output of the engine speed sensor, such as rev limiters, idle speed control and overrun fuel cut off, not to mention complex strategies like anti-lag and launch control on vehicles equipped with them. Problems with these sensors normally result in poor throttle response, hesitations, sudden engine stops and non-start situations.

## COOLANT TEMPERATURE SENSOR (CTS)

This sensor is usually located on the cylinder head itself and is used to monitor the temperature of the engine's coolant. The sensor's resistance changes in direct relation to the coolant temp and normally sends out a voltage of between zero and 5 volts. These outputs are not normally linear, so extreme care should be taken when testing them. Be sure to get the correct data for the sensor in question before presuming a failure.



The ECU will use the data from this sensor to control the base fuel level injected from the map everywhere from absolutely freezing cold right the way up to over 100 degrees Celsius.

Engines need more fuel when cold than they do when hot. A failing or faulty coolant sensor can cause all manner of faults from not starting when cold, to cutting out when hot, along with a whole mixture of problems in between these two examples.

Various modes of operation are based on this information too, such as closed-loop control and idle target speeds, not to mention exhaust gas recirculation programs and charcoal canister purge valves.

## AIR TEMPERATURE SENSOR (ATS)

This sensor is usually located on the air's inlet route into the engine somewhere, or in the plenum itself and is used, as its name suggests, for monitoring the temperature of the air entering the engine.

The sensor's resistance changes in direct relation to the temperature of the air in contact with it and, just like the coolant sensor, normally sends out an output voltage of between zero and 5 volts. These outputs again are not normally linear, so take care if testing.

The ECU will use the data from this sensor to control the base fuel level under all modes of injection as the air temperature relates directly to how much oxygen is available within the air due to a change in density. The colder the air temperature, the more oxygen is present, and vice versa so the engine obviously needs more fuel when the air coming in is cold than it does when hot. See why you fit bigger intercoolers now?

A failing or faulty air temperature sensor can also cause all manner of faults from not starting when cold, to cutting out when hot, along with a whole mixture of problems in between. Again there are various different ECU strategies dependant largely on this information, but the most notable are boost pressure control, water injection and anti-lag (when fitted).

## MANIFOLD ABSOLUTE PRESSURE SENSOR (MAP)

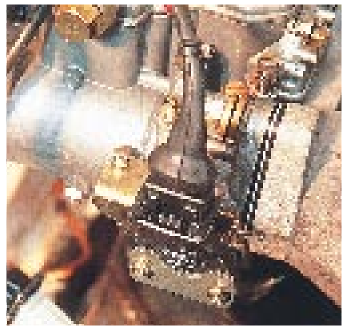
The Manifold Absolute Pressure sensor (or MAP sensor for short) is without doubt the main and most important input for the speed density system. This sensor, as its name suggests, sends a signal to the ECU that accurately reflects the air pressure within the engine's intake manifold. What it does is create a voltage that is directly proportionate to the vacuum or boost pressure that is present in the manifold between the inlet valves and the throttle butterfly.

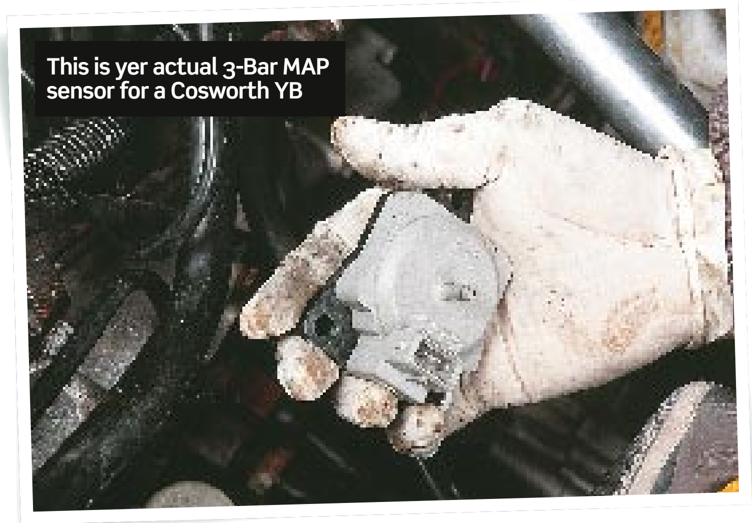
Most cars run a MAP sensor as standard that can read 2 bar of absolute pressure. That's 1 bar below atmosphere (-15 psi) and 1 bar above atmosphere (+15 psi) as an example — 15 psi may be zero volts, whereas +15 psi may be 5 volts with the scale being quite linear in between.

If you intend to run pressures above this, then you will normally be advised to upgrade the sensor to one which can read more, such as a 3 bar sensor. As its name implies, a 3 bar MAP sensor can read 1 bar below atmosphere and 2 bar above atmosphere.

You can't just swap a 2 bar for a 3 bar without altering the program in the ECU as the voltage output of the 3 bar sensor is normally still zero-5 volts, so your ECU on a 2 bar ECU program is set to understand that when the MAP sensor sees 15 psi at the intake plenum it will send out 5 volts and in turn the ECU will then inject enough fuel for 15 psi.

Of course, your shiny new 3 bar will not output 5 volts until it's got 2 bar of boost, and we need more fuel for that extra boost. Make sure your ECU has the correct information at all times or you'll pay the price from ill-informed meddling.





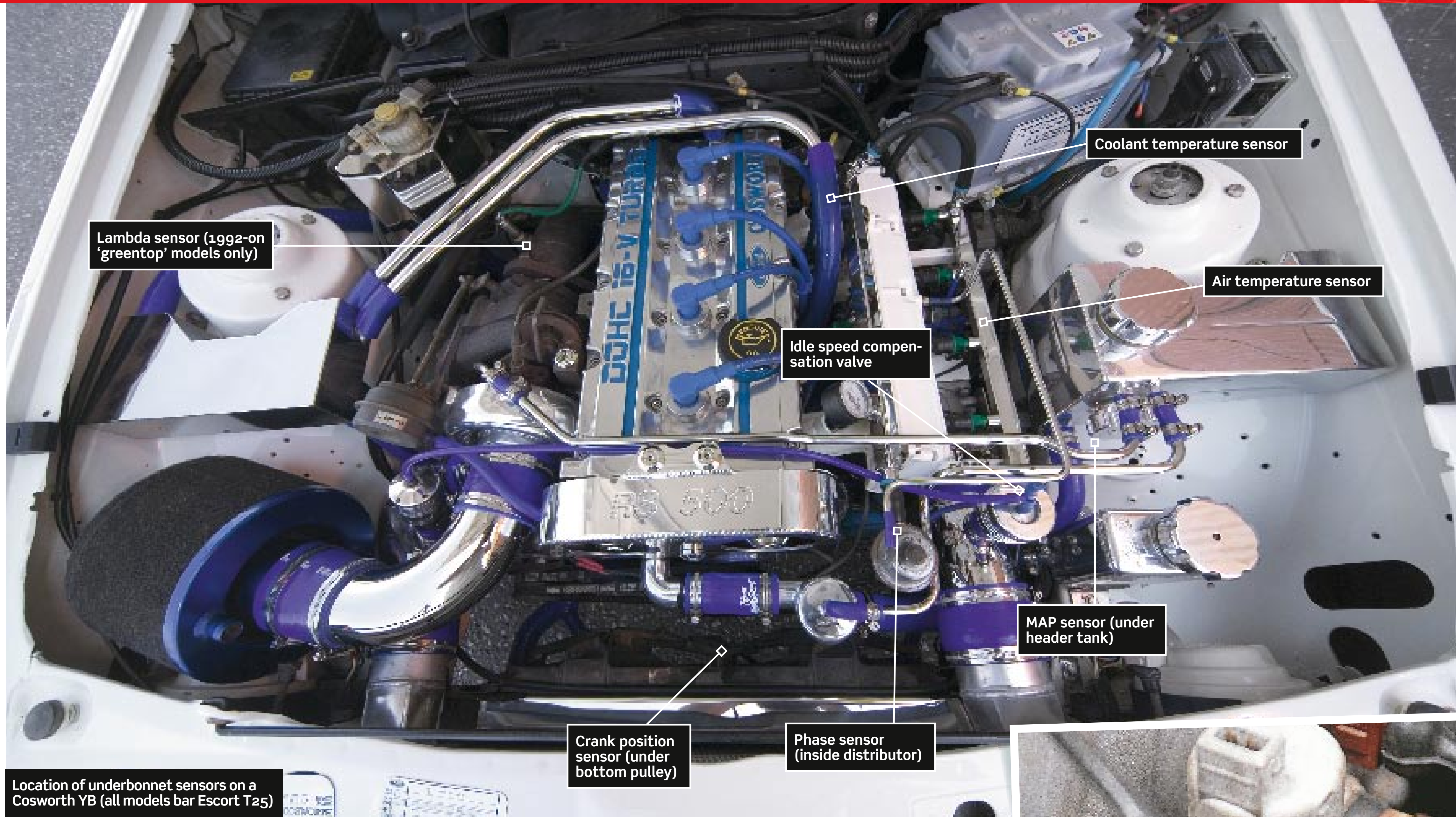
This is yer actual 3-Bar MAP sensor for a Cosworth YB

## THROTTLE POSITION SENSOR (TPS)

The throttle position sensor is normally a variable resistor which converts the angle of the throttle plate into a voltage. On most cars this voltage is zero to 5 volts.

For example, throttle closed may send zero volts to the ECU, half open send 2.5 volts and fully open, 5 volts, with a nice linear output covering all available positions between open and closed. This output ensures that the ECU has very accurate information with regard to where exactly the throttle plate is situated, as well as how fast it is moved.

This information is used mostly to fine-tune the fuel delivered to the cylinders for driveability and fuel economy, although it is also used to deliver the correct mixture under wide open throttle conditions. A sensor error can cause all manner of problems from simple hesitations in traffic, to a melted engine at wide open throttle. Also common are an idle speed instability problems and popping noises in the exhaust on overrun, as the input is also used to control strategies such as overrun fuel cut off (helps economy by switching off fuel on overrun) and idle speed control valve control (fast idle when cold and compensations for heavy electrical load). So, if the ECU doesn't actually know the throttle is closed due to this sensor malfunctioning, it won't correctly activate these strategies, which will cause problems.




Location of underbonnet sensors on a Cosworth YB (all models bar Escort T25)

## PHASE SENSOR

This sensor (right) feeds information back to the ECU in a waveform. The phase sensor needs to see two pulses about 5 degrees wide, spaced at 180 crank degrees (90 cam degrees) apart with the first occurring about 45 degrees after TDC on cylinder one.

These pulses are not as critical as the crankshaft sensor ones. They're used to tell the ECU which crank pulse is TDC and which is 90 degrees BTDC, and on which cylinder. The sensor can be mounted on any shaft running at half engine speed (distributor or camshaft). This information is used primarily for injection sequencing. Problems here normally relate to misfires.

## KNOCK SENSOR (KS)

The knock sensor is utilised by the ECU to keep an eye out for engine-destroying detonation. When any is sensed it allows the ECU to react accordingly to safeguard the engine. In most cases this means backing off the ignition timing a bit until the knock is eliminated.

How it works is actually very clever: inside a knock sensor is a piezoelectric element. These useful little units create their own electricity when vibration is applied to them, and in the case of knock sensors these units are tuned to react to the frequency that knock generates — around 7-12 kHz.

A faulty knock sensor can create some really weird faults, quite commonly the sign of a faulty one is an engine that works very well and does all the right things but is kind of dull and low on power when you really need it. This is because the ECU thinks that the engine is knocking and is retarding the timing but only under full load conditions.

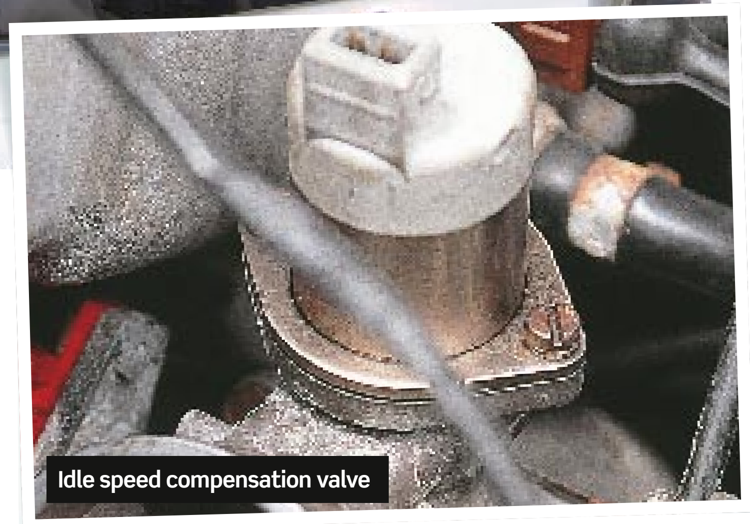
## IDLE SPEED COMPENSATION VALVE (ISCV)

Notice I didn't call it an Idle Speed 'Control' Valve? That's because it doesn't really control the speed at all, it just compensates for idle fluctuations in most installations.

The way it works is quite simple: it's a solenoid that, using a plunger, blocks or unblocks a channel that allows air to flow from one side of the throttle butterfly to the other. This arrangement means that the solenoid can control how much air is allowed to bypass the butterfly, thus controlling the idle speed.

The ECU sends a signal down to this valve and can open or close the valve at will, thus raising or dropping the idle speed to a determined level. The reasons for it to exist, commonly, is to give a slightly higher idle speed under cold conditions and to compensate for high engine loads at idle that would affect idle stability such as air conditioning or lots of electrics.

Errors in these units normally show themselves as poor idle performance; stalling when cold and idle instability issues when hot.



Idle speed compensation valve

## LAMBDA SENSOR (O2)

The exhaust gas oxygen sensor (also known as HEGO or Lambda) is the key sensor in the engine management's fuel control closed-loop feedback circuit. The ECU uses the sensor's input to compose the mixture correctly by leaning off the mixture when the sensor reports too rich and richening up the mix when the sensor reports it too lean.

Lambda sensors work by producing a voltage signal that relates to the amount of unburnt oxygen in the exhaust. An oxygen sensor, like a knock sensor, generates its own voltage.

When hot (at least 250 degrees C), the zirconium element in the sensor's tip produces a small voltage that varies according to the amount of oxygen in the exhaust when compared directly to the ambient oxygen level in the outside air. The greater the difference, the higher the sensor's output voltage. The sensor output ranges from around 0.1 volts (lean) to 0.9 volts (rich). A chemically-perfect or 'stoichiometric' fuel mixture of 14.7 parts of air to 1 part of fuel gives an average reading of around 0.45 volts. However, it's worth noting that the Lambda sensor's output voltage does not remain constant, it actually flip-flops back and forth from rich to lean.

Every time the voltage reverses itself and goes from high to low or vice versa, it's called a cross count. A good sensor should fluctuate from rich to lean about once per second. If the number of cross counts is lower than this, it tells you the o2 sensor is getting sluggish and needs to be replaced.

Most good-quality sensors will cycle from rich to lean in about 50 to 100 milliseconds, and from lean to rich in 75 to 150 milliseconds. This is referred to as the transition time. If the o2 sensor is taking significantly longer to reverse readings, this too is an indication that it is getting sluggish and may need to be replaced.

Observing the sensor's waveform on a scope is a good way to see whether or not it is slowing down with age. Problems with the sensor will normally cause hesitation problems during acceleration as well as poor fuel economy and driveability.

## MASS AIR FLOW SENSOR (MAF)

The extra sensor that will most definitely tell the two systems apart is the addition of an air-mass meter. This sensor revolutionised the engine management world as it meant air 'flow' could now be measured as well as the density, and this opened up new avenues.

There are two common designs of MAF sensors used in today's vehicles: one produces a variable voltage output (analogue); and the other produces a frequency output (digital). In either case their operations are both very similar. Both outputs can be measured by an oscilloscope or a digital voltmeter that can measure frequency. Both of the current designs operate under a principle known as 'hot wire'.

Basically, a constant voltage is applied to a heated film or heated wire. This film or wire is positioned within the air stream, usually in an airflow sampling tune within the airflow meter's body and is heated by an electrical current that the driver circuit supplies.

As air flows across the hot wire it cools it down, requiring more current to keep it up to temperature. This current used is converted to a frequency or a voltage which is sent to the ECU so its programming can interpret it as mass airflow.

Mass airflow sensor

Failing airflow meters normally produce poor driveability, economy and performance.

Additional sensors are commonly found fitted to the mass airflow. They are by no means a necessity, but certainly add refinement to the systems that they are programmed to work with. Here are a couple of examples:

## FUEL TEMPERATURE SENSOR (FTS)

This one works just like a coolant temperature sensor but it is placed in the fuel rail instead to monitor the temperature of the fuel.

Petrol injection quantity varies a small amount with temperature so having this sensor allows us to feed a zero-5 volt signal back to the ECU that represents the temperature of the fuel about to be injected, allowing it to make any necessary adjustments. Only fuel economy normally suffers if these are faulty, although an open circuit one can cause non starts and bad driveability.

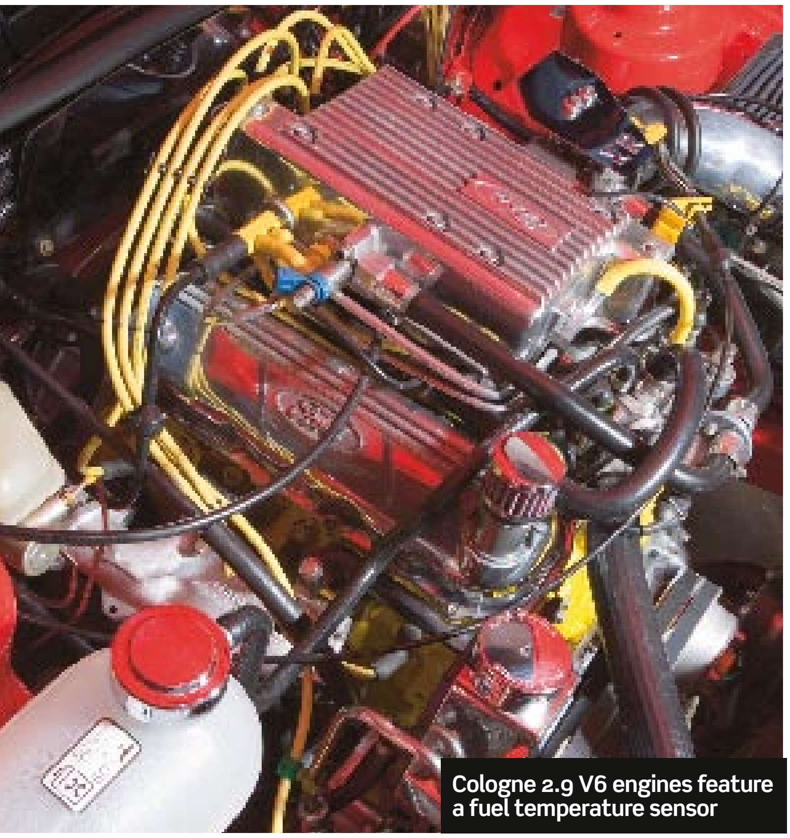
## VEHICLE SPEED SENSOR (VSS)

This sensor, as its name suggests, feeds back information to the ECU relating to vehicle speed. Often sent as a 0-5 volt waveform it allows the ECU to monitor road speed and control systems as required such as road speed limiters or more commonly extra idle strategies to reduce emissions when still rolling to a standstill.

## POWER STEERING PRESSURE SWITCH (PPS)

This is a switch that measures high pressure within the power steering system via a zero-5 volt output. The ECU uses information from this sensor to understand high steering effort so it can possibly counteract any tendency for the vehicle's engine speed to drop a lot with high steering use, such as parking.

Failures here can see the engine always have a high idle speed, or perhaps stall when trying to get in a tight parking space.



Cologne 2.9 V6 engines feature a fuel temperature sensor

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## NEXT MONTH

**There you have it, you now have a little idea what the vast majority of the engine management sensors do and how they do it, along with a clue what the ECU wants to see the info for.**

**Next month we will look at why speed density and mass air flow systems are so very different and get into how the ECU actually does its job.**