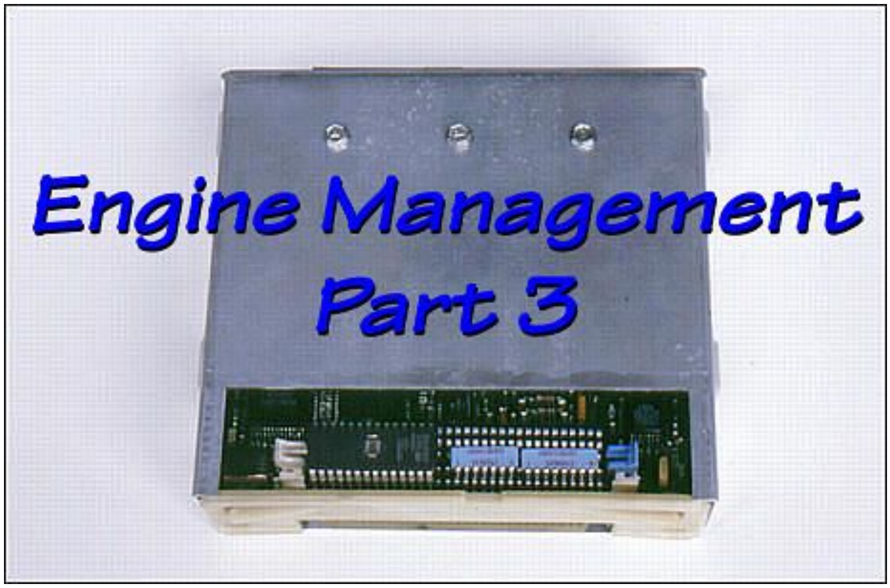



# Engine Management Systems, Part 3

The ECU is the computer that runs the engine. It takes note of what the input sensors are telling it, consults the internal program, and then spits out the right injector opening times and other outputs. So how does it do this?

*By Julian Edgar*

When you open up an ECU you'll be confronted with a view of hundreds of tiny parts mounted on printed circuit boards. It can be quite overwhelming - your first thoughts will probably be who (other than an electronics engineer) is going to be able to modify this? But rest easily - you **don't** need to know the function of every tiny electrical component to understand something about how the ECU works. Instead, it's easiest to simply think of it as an electronic decision-making box that has inputs and outputs. We've already covered the input sensors and the outputs, so what about the decision making part?

Most of the components inside an ECU are concerned with switching on and off the electrical loads like the injectors, and converting the analog output of the coolant and other sensors into a digital form that can be understood by the ECU. The actual program that makes the engine management decisions is normally located on only one chip. GM make this easy to see because in some of their ECUs they put all of the program (and a few other things) onto a detachable plastic module. They call this module the Mem-Cal, which is short for Memory Calibration.

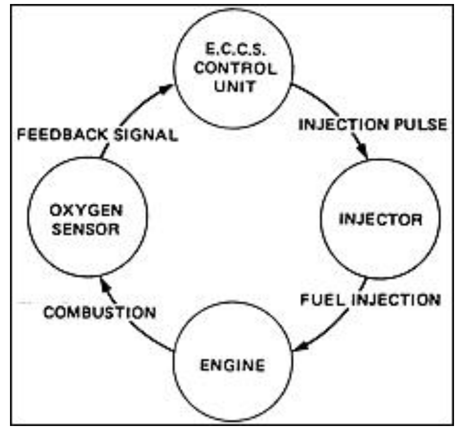
So what goes on in the software that actually runs the engine? Many people have hacked into car ECUs and have caught glimpses on what goes on inside, changing a byte here and a byte there. However, as far as I know, computer genius Ken Young (of Australian company http://www.efidirect.com.au EFI Direct) is the only person to have developed commercially-available software that lets you see in plain English what's going on in factory management software. His Kalmaker programs for GM-Delco ECUs provides a stunning window into the complexity of standard management systems. Incidentally, not only does EFI Direct's software allow access to the program, but it also lets you change whatever parameters you want. Much of the information used here was derived from real program examples in the Delco software.

Rather than try to decipher everything that's going on, we'll look at some of the general strategies adopted by the ECUs in most cars.

## Closed Loop

When you're driving along steadily at city road speeds, there's very little throttle being used. In these conditions, the ECU is programmed to keep the air/fuel ratio close to 14.7:1 - the air/fuel ratio at which the catalytic converter works best at cleaning up the exhaust. The oxygen sensor (that's the one sniffing the exhaust gas) sends a voltage signal back to the ECU, telling the ECU whether the car is running rich or lean. If the engine's running a little rich, the ECU will lean it out. If it's a bit lean, the ECU will richen the mixtures. The oxy sensor then checks on what the effect of the change is.

This constant feedback loop looks something like this:




It's called closed loop running when the ECU is working in this way. Closed loop running on most cars occurs when the engine is up to operating temperature; the throttle opening is not very large or very small; and in certain speed ranges. In normal driving, this means that the ECU operates in close loop mode for a great deal of the time. (Note that 'ECCS Control Unit" in Nissan-speak for the ECU!)

However, the ECU can switch out of closed loop running in an instant. You can be driving along gently in closed loop and then mash the throttle to the floor. The ECU instantly switches out of closed loop, ignoring the output of the oxygen sensor and substantially richening mixtures. None of this can be felt by the driver, although a sensitive listener can sometimes detect at idle the very slight changes in engine note as the mixtures go marginally rich then marginally lean in a constant cycle. Closed loop running relies on having the oxygen sensor in good condition - if it's defective, the car won't go into closed loop, and fuel economy and emissions will suffer.

## Self Learning

In addition to closed loop running, the oxygen sensor is also used as part of the ECU's self-learning system. Imagine for a moment that the fuel filter in your car is a bit blocked so that the mixtures are always a bit lean. The oxygen sensor measures this and tells the ECU to richen up the air/fuel ratio. But it's a pretty inefficient system if every day the oxy sensor has to tell the ECU the same story! Instead, what happens is this. The ECU knows that the mixtures are always a bit lean, and so it **permanently** richens up the mixtures. It has "learned" that richer mixtures are needed, and then always runs this correction. If you change the filter, the ECU will then gradually re-learn the new requirements. This self-learning process occurs in most ECUs and is totally dependent on the health of the oxy sensor.

However, a typical oxygen sensor used in mass-produced cars can measure the air/fuel ratio only over a quite limited range. The sensor is designed to be very sensitive around 14.7:1 air/fuel ratios, because that's where its input is most important. This lack of sensitivity at leaner (and richer) air/fuel ratios means that the next type of ECU behaviour isn't monitored in the same way by the oxy sensor. And what sort of behaviour is that? - lean cruise.

## Lean Cruise

We already know that rich mixtures are needed for power and leaner mixtures for cruise. But what about on a l-o-n-g gentle drive? Even leaner mixtures can then be used, improving economy further. And that's just what a "lean cruise" ECU does. It sees how long you've been maintaining a steady speed for, how much throttle you're using and whether the engine's up to temp, and if all of these factors are okay, it starts to lean out the mixtures. Second by second the air/fuel ratio gradually gets leaner, until you're moving along just sipping petrol. If you put your foot down, instantly the ECU forgets all about lean cruise - until the right conditions are met again. Not all ECUs have a lean cruise function but most cars of the last few years are so-equipped. Lean cruise is a good example of where the standard engine management system is in most cases better than an aftermarket programmable system.

## Open Loop

At full throttle, the oxygen sensor is always ignored. This is called open loop running. In this situation, the ECU bases its decisions totally on the information that has been programmed into it. If the ECU senses a high load, it will open the injectors for a long time and squirt in large amounts of fuel. The ECU uses a table of information (called a map) that tells it how to long to open the injectors for at all the different engine loads. This characteristic means that self-learning cannot be used (or relied upon) to cater for the increased full throttle fuel supply required for engine mods that increase power. However, self learning often does help in the changed requirements occurring in part throttle conditions.

Most ECUs also use their pre-programmed maps of information to spit out the right ignition timing for the situation, based on what the sensors are telling it. However, a few cars use the feedback of the knock sensor in a self-learning approach similar to that done with the oxygen sensor on the fuel side of things.

## Rev Limiting and Injector Cuts

All engine management systems use a rev limiter. Some limiters completely cut off fuel at the prescribed engine speed, withholding it until you're 500 rpm below the limit. Hitting this "bed of nails" limiter makes you reckon that you've just broken the crankshaft! Other rev limiters cut off the spark (or injectors) of individual cylinders one after the other, so that you can barely feel that you have reached the max allowable rpm. These soft limiters mean that the car can be used right to the rev limit without a worry.

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. The injectors come back on again when engine revs drop to around 500rpm above idle. If you watch the tacho closely you can see the needle lift a bit when the injectors resume their flow. Injector shut-off benefits both fuel economy and emissions and is one of the ECU outcomes reliant on the input of the speed sensor.

## Self Diagnosis

When EFI cars were released everyone had a great time saying how unreliable they were going to be - but engine managed cars have generally proved to be very reliable indeed. One reason for this is that the ECU has back-ups if a sensor fails. For example, if the coolant temp sensor becomes defective (or the wire to the sensor is damaged), the ECU figures out that the coolant temp sensor is down and ignores it. Instead of measuring coolant temp, the ECU might rely only on the intake air temp sensor. Some ECUs can do without all but a couple of inputs and still keep the engine running.

All engine management systems of the last 15 years or so have what's called a "self diagnosis" ability. That means, you can ask them and they'll tell you what's wrong with them! For example, imagine the intake air temp sensor wire is broken. If you put the ECU into self diagnosis mode (usually by just linking two terminals in a connector or by turning an adjustment on the ECU), the ECU will indicate that it's the air temp sensor that has the problem. Most ECUs communicate this information by flashing the Check Engine the right number of times, with the list of codes available in the workshop manual.


The Kalmaker software can also use the diagnostic link to display real-time input and output values, as shown here.

Engine Management, Part 1
Engine Management, Part 2 - The Outputs