Warp Sp

Modern car engine

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In the world of engine tuning, spanners and screwdrivers have been replaced by palmtops or PCs and flash programming routines. These days even the bonnet can remain down and the ECU need not be opened. Via OBD a quiet runabout can be transformed into a roaring sports car.

It is well-known that a modern car is filled to the brim with electronics. In 1990 there were only a couple of ECUs per vehicle. That number has now increased to 10 or 50 or even more ECUs per car. In addition to the engine controller and ABS controller we now also see dashboard-, network-, air conditioning-controllers etc. emerge. Furthermore, the computing power is ever increasing as well (see **Figure 1**).
The necessity of more computing power is driven mostly by the increased emission requirements and diagnostic abilities. Direct injection engines in particular, require a lot of computing power because of their multiphase fuel injection. An example of the tasks and processes that a modern ECU deals with are outlined in **Figure 2**. Some of the ICs that we are likely to find in an ECU are:

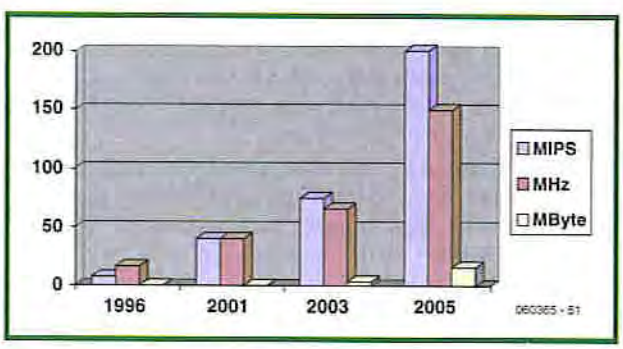

Figure 1. Average number of MIPS of microcontrollers used in ECUs.

- a voltage regulator and processor watchdog;
- a driver IC with SPI diagnostic interface / SPI or PWM input;
- a CAN-bus interface IC;
- 2 MHz 8-bit microcontroller with 8 kilobyte flash memory on board;
- and a 40-MHz, 32-bit microcontroller with 2 MB flash memory on board.

ECU reprogramming

To improve the performance of the engine you can interfere electronically with the engine controller. Professionals with a lot of expertise can change the parameters and

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optimisation in the electronic garage

J2534 standard

The J2534 standard came about to enable garages that are not part of a brand franchise to carry out programming operations on ECUs without having to invest in expensive, proprietary equipment.

It is easily possible that a software update is required to ensure that a car conforms again to the emission requirements. This standard makes that easier. Unfortunately, not all manufacturers participate in this (yet).

The J2534 standard is sometimes also called the pass-thru standard. To be able to program an ECU, software from the manufacturer is required, as well as hardware that complies with the J2534 standard. The number of manufacturers that support the J2534 standard grows every year. To buy the programming software a visit to the manufacturer website often suffices, Honda for example: *http://techinfo.honda.com/rjanisis/RJAAI001_tools2.asp?home=Y*

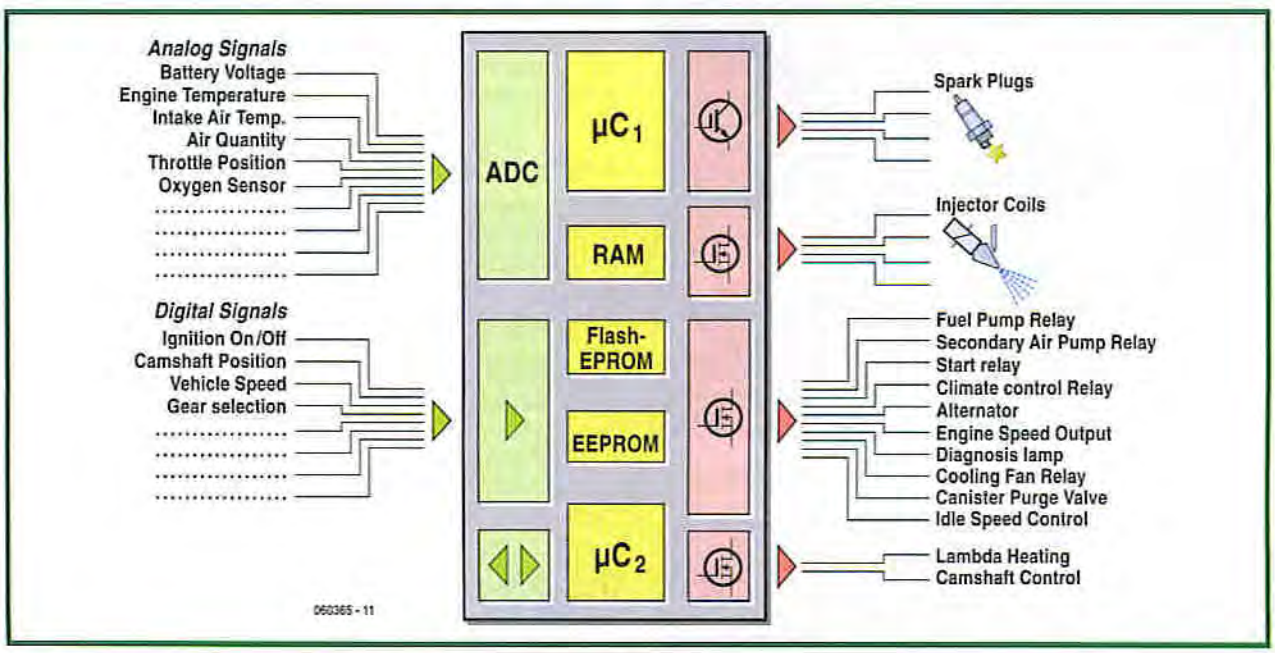

Figure 2. The Hardware Engine Controller. This keeps an eye on an ever increasing number of sensors.

Legislation

The car manufacturer is legally required to take various precautionary measures so that unauthorised programming of the various controllers is not possible. This is mostly to prevent an increase in exhaust emissions. However, if there is a change in the aspiration of the engine, perhaps because of a change in exhaust system, it is often desirable to change the ECU calibration so that the emission requirements are again complied with.

It may not be formally permitted to change the program, but it is actually desirable to return the air/fuel ratio back to the correct value.

It is, for example, well-known that a Subaru Impreza is adjusted quite rich (here is where the manufacturer slightly overshot the concept of 'safe engine adjustment' or perhaps the shareholders of the oil sheiks) and a little bit of 'electronic meddling' can result in not only more engine power, but also – at partial load – lower fuel consumption and therefore a lower emission of CO_2!

Whatever changes are made to a car engine, in the UK, MOT approval will determine whether or not a vehicle is allowed to go on the road.

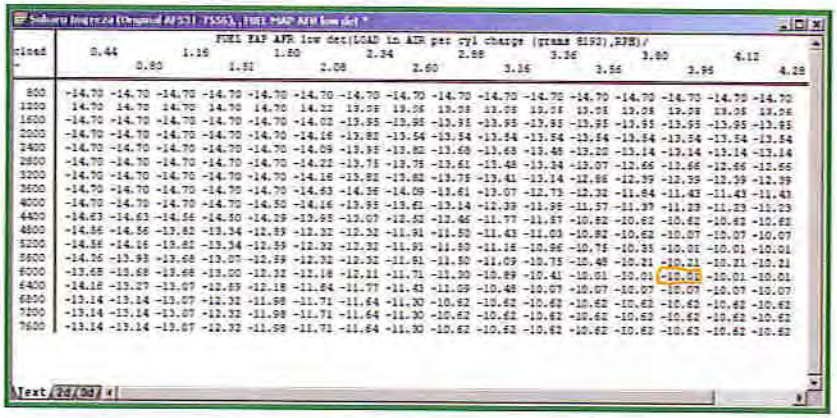

Figure 3. Example of a fuel table.
Based on this table the ECU looks up what the ratio between fuel and air needs to be for a certain engine load, temperature and engine speed.

Figure 4. Subaru-programming with the handheld programmer from www.fastchip.nl

tables that are stored in the ECU. These changes make it necessary to recalibrate the controller. A change in the exhaust and/or intake system changes the aspiration of the engine to such an extent that it will no longer comply with the emission standards that are legally defined. The factory settings (calibration) are, after all, based on a standard intake and exhaust system.
Now that more air is sucked into the engine — at least that is the intention if more performance is required — more fuel needs to be injected as well.
The amount of fuel supplied is typically looked up from a table by the ECU based on the following main parameters (see **Figure 3**):

- engine load;
- engine speed;
- engine temperature.

Along the Y-axis we find the engine speed and along the X-axis the engine load. The engine temperature is looked-up from another table. As an example we take 6000 rpm (revolutions per minute) and 3.96 grams of air per cylinder. We can then see that the AFR-value is 10.01. In this case therefore, 1 part fuel to every 10 parts of air. If, for example, we enter the value 9.0 in the table, then the effective injection time will increase to get more fuel into the cylinder.
Obviously the correct values have to be entered to prevent expensive engine damage and maintain conformance to emission requirements.

Programming via OBD

A lot is involved in order to program new table values into the ECU. In the past it was a case of desoldering the (E)PROM and replacing it with a version with the new code. These days all ECUs are provided with flash memory, which may or may not be a separate chip. Access to the ECU memory is always possible via OBD. This requires that the ECU is first placed into a special security mode. To put the ECU in security mode you need to ask for a 'seed'. This needs to be answered by the programmer with the correct 'key'. There are often multiple levels of security. For some cars a ready-made solution is available in the form of a handheld programmer.

Hard and software

The hardware provides for proper communication between the software and the ECU while programming. Consequently, the hardware has to have the right kind of interface, such as ISO, CAN, etc. and support non-standard baud rates such as 10,400 or 15,625 baud (bits/s). In some cases a programming voltage is also required. But in most cases standard OBD-hardware will suffice.
If the car manufacturer supports the J2534 standard, then it is enough to buy a J2534 hardware interface. See [1], for example. Software is often available from the manufacturer of the car. See also the inset *J2534-standard*.
Programming software often makes use of the service modes, as described in the SAE J2190 standard *Enhanced E/E Diagnostic Test Modes*, see [2].
The most common J2190 service modes for re-programming are:

$10 start diagnostic service
$20 stop diagnostic service
$27 ask for security access (seed, key)

$34 ask for upload to controller
$35 ask for download from controller
$36 data transmission to/from controller
$37 ask transmission exit
$3D write to memory

Although the service modes are described in the SEA J2190 standard *Enhanced E/E Diagnostic Test Modes*, the parameter identifiers (PIDs) are manufacturer specific. The manufacturer determines the programming order and security access according to their requirements.
In this way the security key could be 32 bits long, but it just as well be 128 bits long.

Reverse engineering

When the manufacturer is not prepared to supply the necessary information and also does not make available any programming software, then the only option that remains is *reverse engineering* of the controller software.
Fortunately there are ever more manufacturers who are prepared to supply programming software to allow their ECUs to be updated.
To discover the correct programming order and to obtain security access the processor code will have to be unravelled. This requires a processor dependent disassembler and interface. Because it is necessary to work at the level of assembly language, this tends to be quite a time-consuming process. Depending on the way the programming operation is implemented by the manufacturer, it may also be necessary to write a kernel and/or flash programming routines just to be able to program the flash at all. This is therefore not a job for the novice.

Car versus computer?

The present-day tuning of cars looks more like hacking than it looks like working in a garage. Because of the far-reaching integration of electronics in the car of today, an increasing number of adjustments can only be carried out electronically. To make things safe and to comply with various legal requirements, the manufacturers lock up the software as much as is possible. Subsequently, several tuning companies such as Fastchip are busy 'decoding' the software in order to be able to make 'adjustments' themselves. This sounds a little like what happens in the pc software arena: hackers who circumvent the protection mechanisms to enable them to make a backup of their beloved Xbox game...

Glossary

AFR	Air Fuel Ratio, ratio between fuel and air.
CAN-bus	Controller Area Network; asynchronous, serial bus system developed for the use in cars.
ECU	Electronic Control Unit; the 'board computer', which controls all the electronics.
MIPS	Million Instructions Per Second; Number of instructions that a controller can process per unit of time (for example, adding two numbers is one instruction).
PWM	Pulse Width Modulation; a standard for signal transmission in which the duty cycle of a rectangular wave contains the information of the signal.
OBD	On-Board Diagnostic; electronic diagnostic system for vehicles.
SPI	Serial Peripheral Interface; standard for a serial interface for a digital signal network.

The holy cow will not disappear from our driveway any time soon while the electronics becomes over more sophisticated. In all likelihood, IT will place an increasing role in the garage of the future. That's quite a promise!

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Web links:

[1] www.passthruxs.com
[2] www.sae.org
[3] www.fastchip.nl

The days that a mechanic got dirty hands when tuning an engine are gone...