Electronic control unit (ECU)

Digital technology furnishes an extensive array of options for open and closed-loop control of automotive electronic systems. A large number of parameters can be included in the process to support optimal operation of various systems. After receiving the electric signals transmitted by the sensors, the ECU processes these data in order to generate control signals for the actuators. The software program for closed-loop control is stored in the ECU's memory. The program is executed by a microcontroller. The ECU and its components are referred to as hardware. The Motronic ECU contains all of the algorithms for open and closed-loop control needed to govern the engine-management processes (ignition, induction and mixture formation, etc.).

Operating conditions

The ECU operates in an extremely harsh and demanding environment.
It is exposed to
- Extreme temperatures (ranging from –40 to +60...+125 °C) under normal operating conditions
- Abrupt temperature variations
- Exposure to fluids (oil, fuel, etc.)
- The effects of moisture and
- Mechanical stresses such as engine vibration

The engine-management ECU must continue to perform flawlessly in the face of fluctuations in electrical supply, during starts with a weak battery (cold starts, etc.) as well as at high voltages (surges in onboard electrical system).

Other requirements arise from the need for EMC (**E**lectro-**M**agnetic **C**ompatibility). The requirements for resistance to electromagnetic interference and for suppressing EMI emissions from the system itself are both very high.

Design

The printed-circuit board with the electrical components (Fig. 1) is installed in a housing of plastic or metal. A multipin plug connects the ECU to the sensors, actuators and electrical power supply. The high-power driver circuits that provide direct control of the actuators are specially integrated within the housing to ensure effective heat transfer to the housing and the surrounding air.

Most of the electronic components are SMDs (**S**urface-**M**ounted **D**evices). This concept provides extremely efficient use of space in low-weight packages. Only the power elements and the plugs are mounted using conventional insertion technology.

Hybrid versions combining compact dimensions with extreme resistance to thermal attack are available for mounting directly on the engine.

Data processing

Input signals

The sensors join the actuators as the peripheral components linking the vehicle and the central processing device, the engine-management ECU. The electrical signals from the sensors travel through the wiring harness and the plug to reach the control unit. These signals can be in various forms:

Analog input signals

Analog input signals can have any voltage level within a specific range. Samples of physical parameters monitored as analog data include induction air mass, battery voltage and intake-manifold pressure (including boost pressure) as well as the temperatures of the coolant and induction air. An analog/digital (A/D) converter within the control unit's microcontroller transforms the signal data into the digital form required by the microcontroller's central processing unit. The maximum resolution of these analog signals is

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5 mV. This translates into roughly 1000 incremental graduations based on an overall monitoring range of 0...5 V.

Digital input signals

Digital input signals have only two conditions: high (logical 1) and low (logical 0). Samples of digital input signals are switch control signals (on/off) and digital sensor signals such as the rotational-speed pulses from Hall-effect and magnetoresistive sensors. The microcontroller can process these signals without prior conversion.

Pulse-shaped input signals

The pulse-shaped input signals with information on rpm and reference marks transmitted by inductive sensors are conditioned in special circuitry within the ECU. In this process interference pulses are suppressed while the actual signal pulses are converted to digital square-wave signals.

Signal conditioning

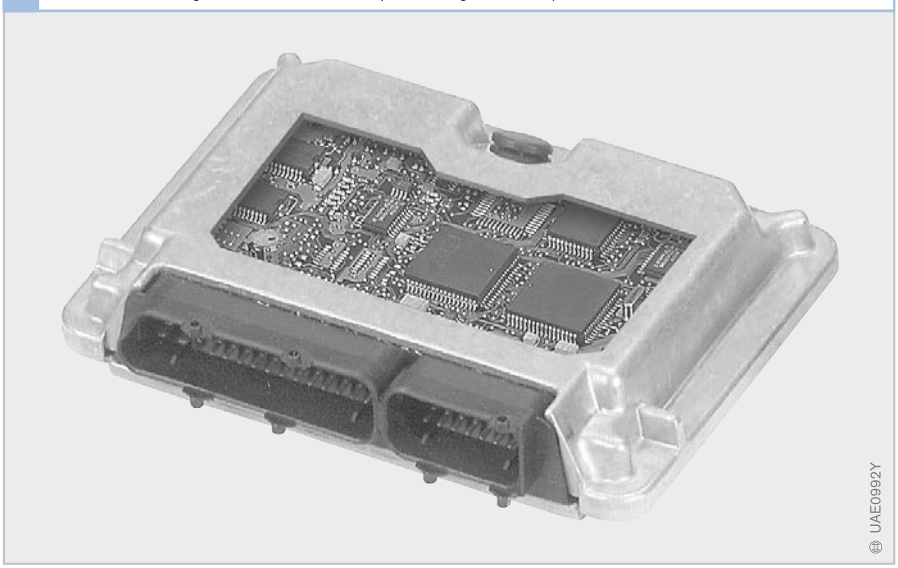
Protective circuits limit the voltages of incoming signals to levels suitable for conditioning. Most of the superimposed interference signals are removed from the useful signal by filters. When necessary, the useful signals are then amplified to the input voltage required by the microcontroller (0...5 V).

Some or all of this initial conditioning can be carried out in the sensor itself, depending upon its level of integration.

Signal processing

The ECU is the switching center governing all of the functions and sequences regulated by the engine-management system. The control algorithms are executed by the microcontroller. The input signals from sensors and interfaces linking other systems (from CAN bus, etc.) serve as the input parameters. The processor runs backup plausibility checks on these data. The ECU program supports calculation of the output signals used to control the actuators.

1 ECU structure, using ME Motronic as an example (housing cover cut open)



Microcontroller

The microcontroller is the central component of a control unit and controls its operative sequence (Fig. 2). Apart from the CPU (Central Processing Unit), the microcontroller contains not only the input and output channels, but also timer units, RAMs, ROMs, serial interfaces, and further peripheral assemblies, all of which are integrated on a single microchip. Quartz-controlled timing is used for the microcontroller.

Program and data memory

In order to carry out the computations, the microcontroller needs a program – the "software". This is in the form of binary numerical values arranged in data records and stored in a program memory.

These binary values are accessed by the CPU which interprets them as commands which it implements one after the other.

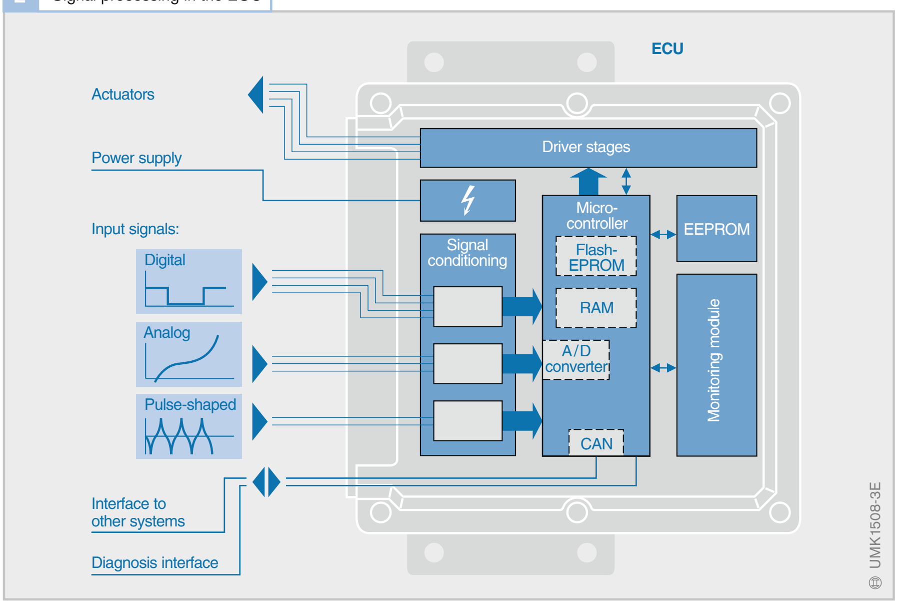
This program is stored in a Read Only Memory (ROM, EPROM, or Flash-EPROM) which also contains variant-specific data (individual data, characteristic curves, and maps). This is non-variable data which cannot be changed during vehicle operation. It is used to regulate the program's open and closed-loop control processes.

The program memory can be integrated in the microcontroller and, depending upon the particular application, extended in a separate component (e.g. an external EPROM or a Flash-EPROM).

ROM

Program memories can be in the form of a ROM (Read Only Memory). This is a memory whose contents have been defined permanently during manufacture and thereafter remain unalterable. The ROM installed in the microcontroller only has a restricted memory capacity, which means that an additional ROM is required in case of complicated applications.

2 Signal processing in the ECU



EPROM
The data on an EPROM (**E**rasable **P**rogrammable **ROM**) can be erased by subjecting the device to UV light. Fresh data can then be entered using a programming unit. The EPROM is usually in the form of a separate component, and is accessed by the CPU through the Address/Data-Bus.

Flash-EPROM (FEPROM)
The contents of the Flash-EPROM can be electrically erased. In the process, the ECU is connected to the reprogramming unit through a serial interface.

If the microcontroller is also equipped with a ROM, this contains the programming routines for the Flash programming. Flash-EPROMs are available which, together with the microcontroller, are integrated on a single microchip.

Its decisive advantages have helped the Flash-EPROM to largely supersede the conventional EPROM.

Variable-data or main memory
Such a read/write memory is needed in order to store such variable data (variables) as the computational and signal values.

RAM
Instantaneous values are stored in the RAM (**R**andom **A**ccess **M**emory) read/write memory. If complex applications are involved, the memory capacity of the RAM incorporated in the microcontroller is insufficient so that an additional RAM module becomes necessary. It is connected to the ECU through the Address/Data-Bus.

When the control unit is disconnected from the power supply, all data stored in the RAM is lost (volatile memory). However, the next time the engine is started the control unit has to have access to adaptation data (learned data relating to engine condition and operating status). That information must not be lost when the ignition is switched off. In order to prevent that happening, the RAM is permanently connected to the power supply (continuous power supply). If the battery is disconnected, however, the information will nevertheless be lost.

EEPROM (also known as the E^2PROM)
Data that must not be lost even if the battery is disconnected (e.g. important adaptation data, codes for the immobilizer) must be permanently stored in a nonvolatile, non-erasable memory. The EEPROM is an electrically erasable EPROM in which (in contrast to the Flash-EPROM) every single memory location can be erased individually. Therefore, the EEPROM can be used as a non-volatile random-access memory.

Some control-unit variants also use separately erasable areas of the Flash-EPROM as nonvolatile memories.

ASIC
The ever-increasing complexity of ECU functions means that the computing powers of the standard microcontrollers available on the market no longer suffice. The solution here is to use so-called ASIC modules (**A**pplication **S**pecific **I**ntegrated **C**ircuit). These IC's are designed and produced in accordance with data from the ECU development departments and, as well as being equipped with an extra RAM for instance, and inputs and outputs, they can also generate and transmit pwm signals.

Monitoring module
The ECU is provided with a monitoring module. Using a "Question and Answer" cycle, the microcontroller and the monitoring module supervise each other, and as soon as a fault is detected one of them triggers appropriate back-up functions independent of the other.

Output signals

With its output signals, the microcontroller triggers driver stages which are usually powerful enough to operate the actuators directly. For particularly high power consumers (e.g. radiator fan) some driver stages can also operate relays.

The driver stages are proof against shorts to ground or battery voltage, as well as against destruction due to electrical or thermal overload. Such malfunctions, together with open-circuit lines or sensor faults are identified by the driver-stage IC as an error and reported to the microcontroller.

Switching signals

These are used to switch the actuators on and off (for instance, for the engine fan).

PWM signals

Digital output signals can be in the form of PWM (**P**ulse-**W**idth **M**odulated) signals. Such "pulse-width modulated" signals are square-wave signals with a constant frequency and variable signal duration (Fig. 3). These signals can be used to move a variety of actuators (e.g. exhaust recirculation valve, turbocharger actuator) to any desired working position.

3 PWM signals

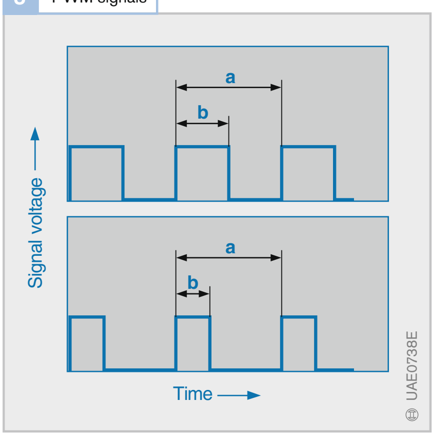


Fig. 3
a Period duration (fixed or variable)
b Variable on-time

Communication within the ECU

In order to be able to support the microcontroller in its work, the peripheral components must communicate with it. This takes place using an address/data bus which, for instance, the microcomputer uses to issue the RAM address whose contents are to be accessed. The data bus is then used to transmit the relevant data. For former automotive applications, an 8-bit structure sufficed whereby the data bus comprised 8 lines which together can transmit 256 values simultaneously. The 16-bit address bus commonly used with such systems can access 65,536 addresses. Presently, more complex systems demand 16 bits, or even 32 bits, for the data bus. In order to save on pins at the components, the data and address buses can be combined in a multiplex system. That is, data and addresses are dispatched through the same lines but offset from each other with respect to time.

Serial interfaces with only a single data line are used for data which need not be transmitted so quickly (e.g. data from the fault storage).

EoL programming

The extensive variety of vehicle variants with differing control programs and data records, makes it imperative to have a system which reduces the number of ECU types needed by a given manufacturer. To that end, the Flash-EPROM's entire memory area can be programmed at the end of the production line with the program and the variant-specific data record (this is referred to as **E**nd-**o**f-**L**ine, or EoL, programming).

A further means of reducing variant diversity is to have a number of data variants (e.g. gearbox variants) stored in the memory, which can then be selected by encoding at the end of the production line. This coding is stored in an EEPROM.

Performance of electronic control units

The performance of Electronic Control Units (ECUs) goes hand-in-hand with advances achieved in the field of microelectronics. The first gasoline fuel-injection systems used analog technology and as such, they were not so versatile when it came to implementing control functions. These functions were constrained by the hardware.

Progress advanced in quantum leaps with the arrival of digital technology and the microcontroller. The entire engine management system was taken over by the universally applicable semiconductor microchip. In microcontroller-based systems, the actual control logic is accommodated on a programmable semiconductor memory chip.

From systems that initially simply controlled fuel injection, complex engine-management systems were then developed. They controlled not only fuel injection but also the ignition system including knock control, exhaust-gas recirculation and a whole variety of other systems. This continuous process of development is bound to continue in a similar vein over the next decade as well. The integration of functions and, above all, their complexity are constantly increasing. This pattern of development is only possible because the microcontrollers used are also undergoing a similar process of improvement.

For a long time microcontrollers of the Intel 8051 family were used until they were superseded at the end of the 1980s by the 80515 series which had extra input/output capabilities for timed signals and an integrated analog-digital converter. It was then possible to create relatively powerful systems. Figure 1 shows a comparison between the performance of a fuel-injection system (LH3.2) and an ignition system (EZ129K) – equipped with 80C515 controllers – and that of the succeeding Motronic systems. With a clock speed of 40 MHz, the ME7 has almost 40 times the processing power of the LH/EZ combination. With the benefit of a new generation of microcontrollers and a further increase in clock frequency on the ME9, this figure will increase to a factor of well over 50.

In the foreseeable future microcontrollers will process more than just digital control sequences. They will have integrated signal processors that will be able to process signals directly, such as signals from the engine-knock sensors, for example.

Advances in the development of semiconductor memory chips are also worthy of note. Complex control programs require an enormous amount of memory space. The capacity of memory chips at the start of the 1980s was still only 8 kilobytes. The ME7 now uses 1-megabyte chips and soon memory capacities of 2 megabytes will be required. Figure 1 shows this pattern of development and likely future trends.

1 Development of electronic control units

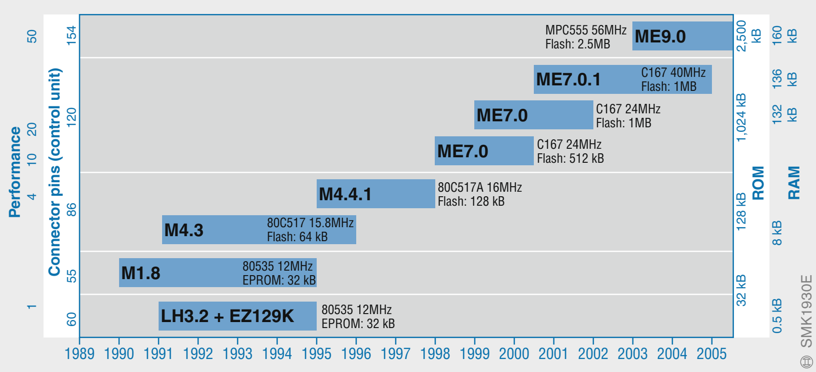


Fig. 1
Chart illustrating

- The performance of engine-management systems
- Number of connector pins on the electronic control units
- Capacity of the program memory
- Capacity of the data memories (RAM)

By way of comparison, the performance of an engine-management system with the very latest technology far exceeds the capabilities of Apollo 13.