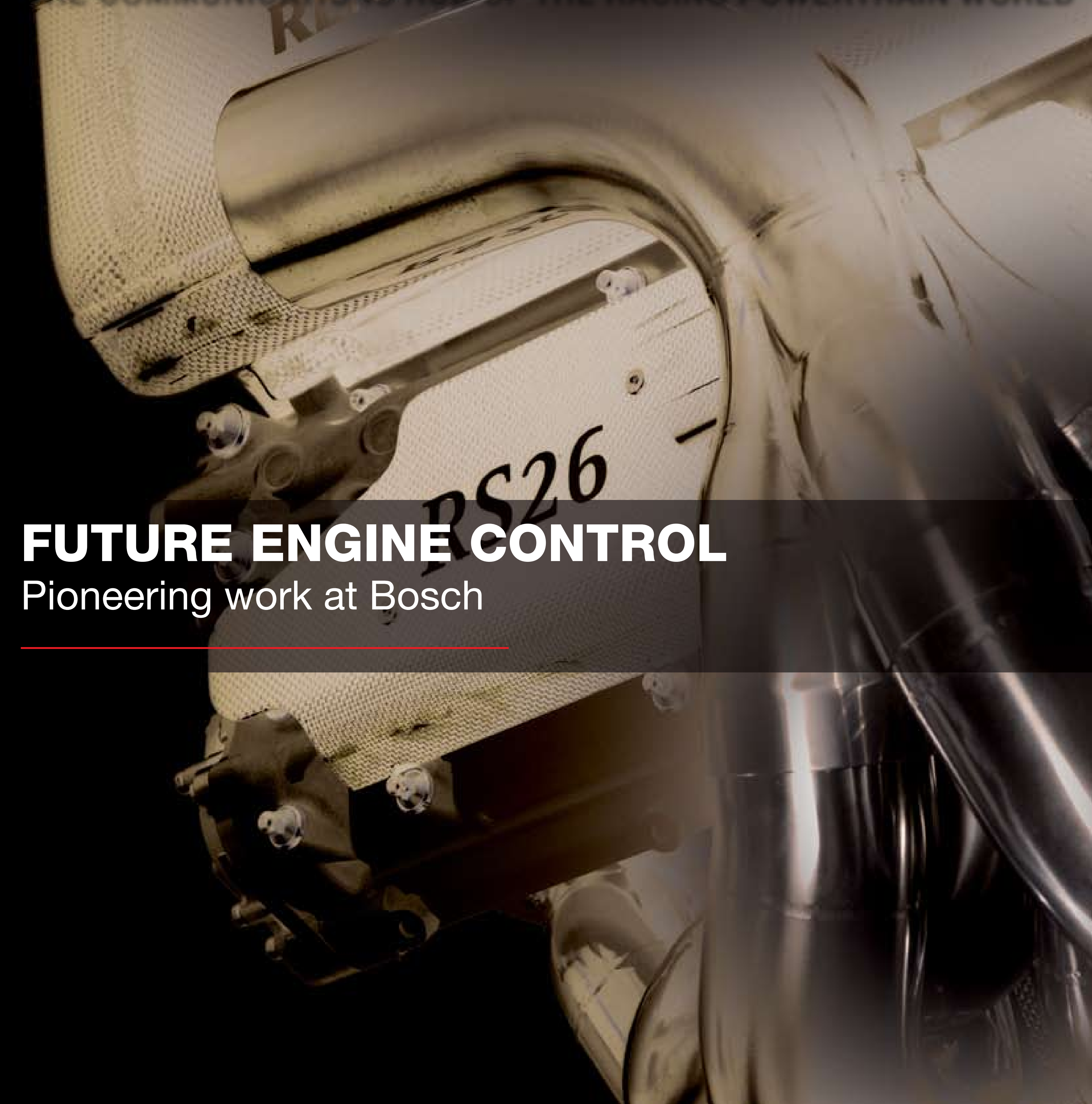
race engine
TECHNOLOGY

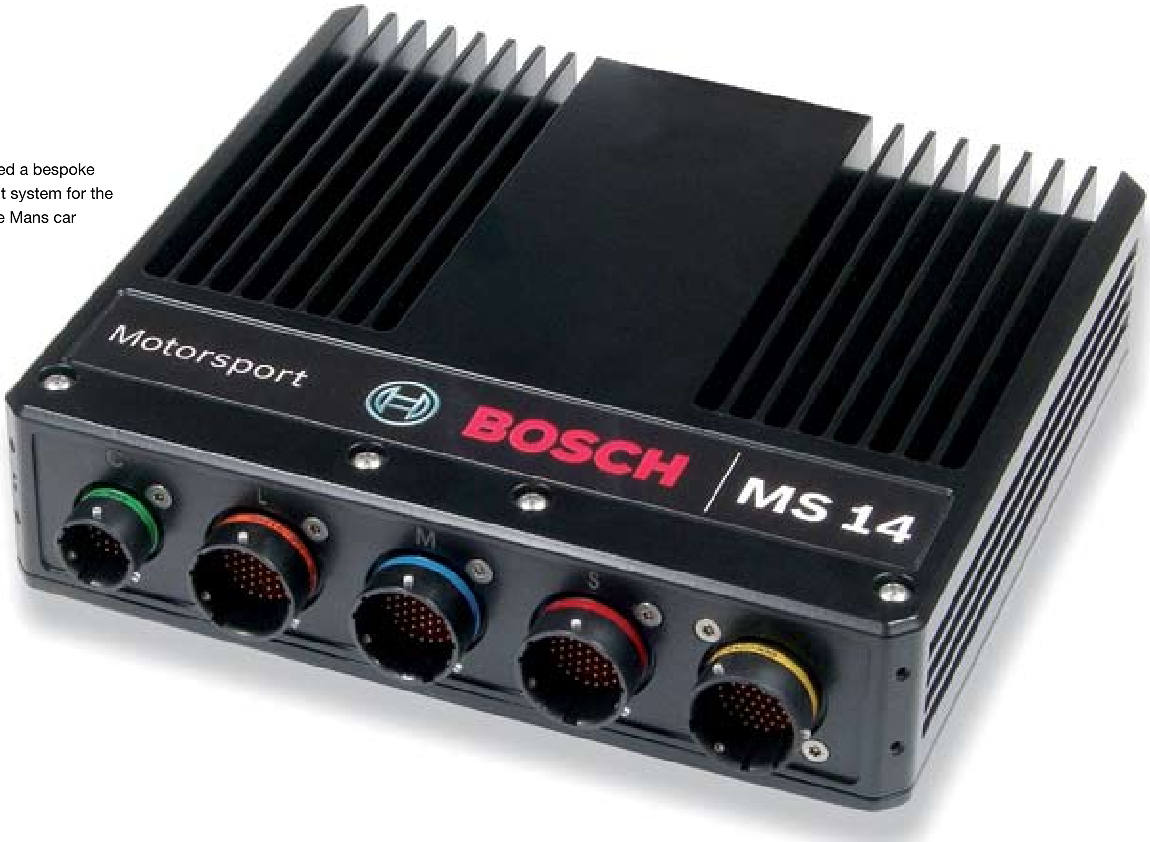
Interview:
HIROSHI ABE, HONDA

THE COMMUNICATIONS HUB OF THE RACING POWERTRAIN WORLD



FUTURE ENGINE CONTROL
Pioneering work at Bosch

Bosch has developed a bespoke engine management system for the Audi turbo-diesel Le Mans car



Ever the pioneer

On a recent visit to Bosch Motorsport we found the company still at the forefront of the development of engine control systems for racing, in particular with its high end diesel equipment and also the exploitation of hybrid and FPGA technology

For over a century Bosch has been at the cutting edge of engine electronics, starting with magneto ignition for some of the earliest racing cars. Bosch was a pioneer of indirect gasoline injection in racing, with early mechanical systems followed by electro-mechanical and fully electronic systems, the latter part of a full engine management system. More recently it has been a pioneer of direct gasoline injection and currently it is pioneering direct diesel injection in racing, using the common rail approach.

On a recent visit to Bosch Motorsport's base at Markgroningen, near Stuttgart in Germany, we looked closely at its diesel engine management system technology and also at the latest developments in both its affordable and its high end gasoline engine management systems.

> "Controlling the number of injections as well as the duration of each provides further accuracy"

DIESEL RACING ENGINE CONTROL

In the compression-ignition engine the fuel/air mixture ignites no matter how lean it is, consequently engine output can be controlled by adjusting the amount of fuel delivered, with no need for a throttle valve. The pumping losses associated with a throttle are avoided so efficiency is inherently higher than that of the gasoline engine.

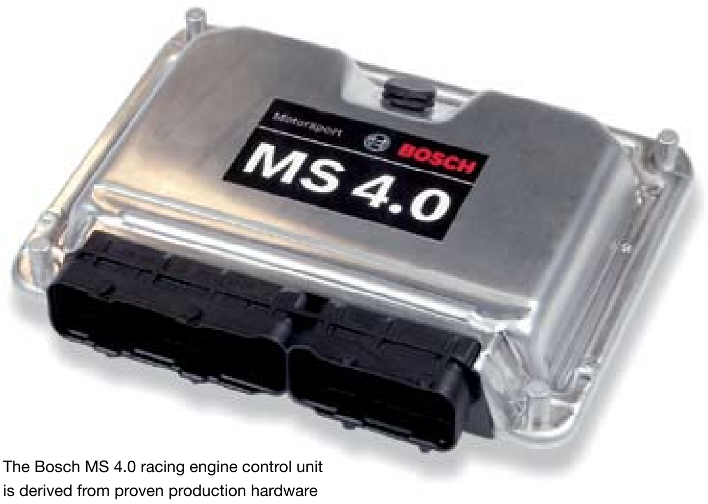
However, to atomise properly the directly injected fuel needs to be at very high pressure, much higher than anything currently seen in the gasoline engine world. Volkswagen traditionally has favoured an individual cam-driven unit injector for each cylinder (as seen on the Mountune-prepared Volkswagen V10 turbo-diesel run at Le Mans in the past by Ian Dawson). Creating the required injection pressure at the cylinder in this manner avoids a lot of high-pressure piping and permits a pressure as high as 2000 bar to be exploited.

An alternative approach is the so called common rail system, where normally the required pressure is created by a single pump and the fuel is stored at high pressure in the common supply rail. Metering control is effected at each cylinder by an electronically controlled injector fed by the common rail. The injector is normally of the electro-magnetic solenoid and needle ('pintle') type. In the road car world, at present the pressure of a common rail system is typically 1600 bar.

To marry high pressure to a high level of metering accuracy, for the Audi R10 Le Mans programme Bosch Motorsport has developed a bespoke common rail type system that operates at "very much more" than 1600 bar with piezo-type injectors providing exceptional precision of control. Piezo injectors exploit the fact that piezo crystals expand rapidly under the influence of a voltage. They operate up to six times faster than conventional pintle-type injectors.

Exploiting the rapid response of a piezo-type injector it is possible to use a number of short injection bursts, in spite of the very narrow 'window' available for fuelling the power stroke. Diesel fuel self ignites within microseconds of entering the combustion chamber and this pulsing approach smoothes the pressure rise.

Clearly, controlling the number of injections as well as the duration of each provides further flexibility and accuracy of engine control. Thus the use of piezo-type injectors offers much enhanced control but that in turn puts a lot more pressure on the requirements of the control system. While the diesel engine control unit (ecu) does not need to make any ignition calculations, compared to a gasoline ecu it has to make a lot more injection calculations on each cycle, these to be ▸



The Bosch MS 4.0 racing engine control unit is derived from proven production hardware

BOSCH THE PIONEER

When it comes to automotive ignition and fuelling systems, Bosch can rightly claim to be a pioneer. Company founder Robert Bosch launched his automotive electrical concern into the world of motorsport from its very early days. Initially Bosch specialised in the ignition system (still its logo features an early magneto) and its equipment was on the 1903 Gordon Bennett race winning Mercedes 90/60hp. This success by Camille Jenatzy in Ireland was the first major international triumph for Mercedes.

Through the twentieth century Stuttgart-based Bosch became synonymous with motorsport successes by Stuttgart firms Mercedes and (founded after the Second World War) Porsche. The 'Silver Arrows' of the thirties used Bosch ignition and the Mercedes Formula One and sportscar racers of the mid fifties pioneered fuel injection in racing, Bosch having branched out into this field. As recounted elsewhere in this issue, the knowledge of fuel injection acquired working with Mercedes was passed on to Vanwall, which won the 1958 World Constructors' Championship using Bosch indirect mechanical injection.

It was the rise of turbo-supercharging that prompted development of electronically controlled injection and of the full engine management system for racing. In 1983 BMW became the first manufacturer to win the World Championship using a 1.5 litre turbo engine and it exploited pioneering Bosch electro-mechanical injection. Working with BMW, at this time Bosch was also in the forefront of the development of car to pits telemetry.

By this stage Porsche was already winning Le Mans and other Group C sportscar races using fully electronic injection as part of a pioneering Bosch engine management system. This 'Motronic' technology went on to win the Formula One World Championship in 1984 with the Porsche-made McLaren TAG turbo engine. That was the first of three successive World Championship titles for the Bosch technology-managed engine.

In sportscar racing a long run of success by Porsche's Motronic-equipped Group C car was followed by the official return to racing of Mercedes. The Bosch-equipped Sauber-Mercedes dominated the 1988 and 1989 Group C seasons. Bosch went on to win Le Mans five times in the nineties, with McLaren, Porsche and BMW. When, this century Audi took its turn to dominate sportscar racing, Bosch was again the engine management system provider. Bosch co-developed pioneering direct gasoline injection in racing with Audi.

Ever the pioneer, Bosch is now the engine control partner for both the Audi and the Peugeot Le Mans diesel projects.

THE BOSCH MOTORSPORT FILE

PRODUCT
Hardware and software for engine and transmission control, including all ignition and injection system components plus sensors, dash displays, communications devices and tools, also starters and alternators

RACING MARKET
All forms of racing

HEADQUARTERS
Markgroningen, near Stuttgart, Germany

KEY PEOPLE
Director: Klaus Boettcher
Marketing: Ulrich Michelt
Head of Applications: Sven Behrens
Head of Software Development: Andreas Becker
Head of Hardware Development: Roger Flattich
Head of Assembly: Hans Loistl
Head of R&D: Oliver Wildner

SCALE OF OPERATION
Total workforce of 80: 100% dedicated to motorsport

BACKGROUND
Established in 2003 as a wholly-owned spin-off from Bosch Engineering, which in turn is a subsidiary of Robert Bosch GmbH

GLOBAL DISTRIBUTION
Agents worldwide. A US office operates out of the Bosch facility in Michigan


Klaus Boettcher

Today employing around a quarter of a million people worldwide, Robert Bosch GmbH is still 93% owned by the descendents of its founder (who died in 1942). Sister company Bosch Engineering GmbH was founded in 1999 with 14 employees. Today it employs more than 700, over a tenth of whom work directly on motorsport through its Bosch Motorsport division.

Formed at the start of 2003, Bosch Motorsport is based in the small town of Markgroningen, some 30 kilometres from the headquarters of Bosch Engineering and a similar distance from the city of Stuttgart, Germany, where Robert Bosch GmbH is located. Bosch Motorsport has its own remote building for reasons of security. It is its own profit centre within Bosch Engineering, which is purely a service provider – all component manufacturing for the group is undertaken by Robert Bosch GmbH.

Engine Management Systems are made at Bosch Motorsport using components sourced from other Bosch plants and various specialist suppliers. The construction of housings is sub contracted while some sensors come from outside of the Bosch group. Injectors and ignition coils are handmade at another Bosch plant to Bosch Motorsport designs. According to the specific application these can be either bespoke items or modified production parts.

Based in a four storey building in the suburbs of Markgroningen, Bosch Motorsport has facilities to make wiring looms, to modify production alternators for NASCAR racing and so forth, together with extensive design, development and testing resources. It works purely on projects for motorsport and it can supply complete electrical systems.

Bosch Motorsport is run by Dr. Klaus Boettcher. His 80 strong staff comprises specialists on software development, hardware development, hardware build and ‘applications’ including track support, with others working in sales and administration. Bosch Motorsport currently has a group of calibration and development engineers working out of the Robert Bosch facility in Farmingham Hills near Detroit. They are developing Bosch Motorsport USA as the company’s North American business grows. With a new contract to supply Grand Am and a push across other forms of US racing, this arm of the operation is set to expand.

Current projects by Bosch Motorsport include Le Mans diesel and gasoline engine engine management systems. At this year’s 24 hour classic it won LMP1 with Audi, GT1 with Corvette and GT2 with Panoz. It also finished runner up on the Paris-Dakar Rallye/Raid with Volkswagen. Bosch Motorsport supplies the ems used by Skoda in the World Rally Championship and that used by Seat in the World Touring Car Championship.

Bosch Motorsport supports Porsche’s racing programmes, including LMP2, GT2 and the Porsche Cup. The company also has a contract to supply the ‘spec’ ecu for the DTM while in most countries a Bosch ems is mandatory for Formula Three racing. In the Formula One arena, of late Bosch Motorsport has been supplying pumps and injectors for use with high-pressure systems, ignition coils, ion current measuring systems and more. In NASCAR the majority of the field uses Bosch alternators and spark plugs.

Bosch Motorsport is starting to look at motorcycle sport. A year ago it purchased an Aprilia 1.0 litre V2 street bike. This has been equipped with a Bosch MS 4 engine management system plus dash display unit and it is currently being evaluated in road testing. It is possible that a bespoke system will be developed, according to how the testing of existing hardware progresses. The next step will be to partner with a motorcycle racing team.

made across just a fraction of that (720 degree) cycle.

The Bosch MS 14 Le Mans diesel engine control system developed for Audi R10 V12 turbo-diesel needs to control its 12 injectors and its two turbocharger wastegates. At Le Mans the Audi was operating in the 3000-5000 rpm range, the drivers shifting at 5000 rpm. The electronic control of the wastegates was, through the ecu, linked to the control of the injectors, with the aim of ensuring each cylinder had the right amount of air and fuel at any given instant.

In addition to dedicated engine control units for the Audi and the forthcoming Peugeot compression-ignition Le Mans contenders, Bosch has a ‘mid range’ common rail direct injection system available for a diesel racing engine, such as might be used in Touring Car racing. This MS 15 system has Mil-spec connectors and is available with power stages suitable for piezo-type injectors. It has been designed on a modular basis, so that it is straightforward for the Bosch Motorsport designers to react to the requirements of new customers, as diesel engines become increasingly popular in motorsport.

AFFORDABLE GASOLINE ENGINE CONTROL

For gasoline-fuelled cars Bosch offers its MS 1 and MS 2 systems for high end applications (with MS 5 in development) while it has MS 3 and MS 4 as more affordable solutions. Where MS 1 and MS 2 use multiple processors, the MS 3 and MS 4 ecus are each based around a single processor. MS 3 exploits advanced ‘hybrid’ rather than printed circuit board (pcb) technology from production whereas MS4 uses more conventional electronic components for additional flexibility. A new version of MS 4 (MS4.3) has been mandated as the spec ecu for Grand Am racing from 2007.

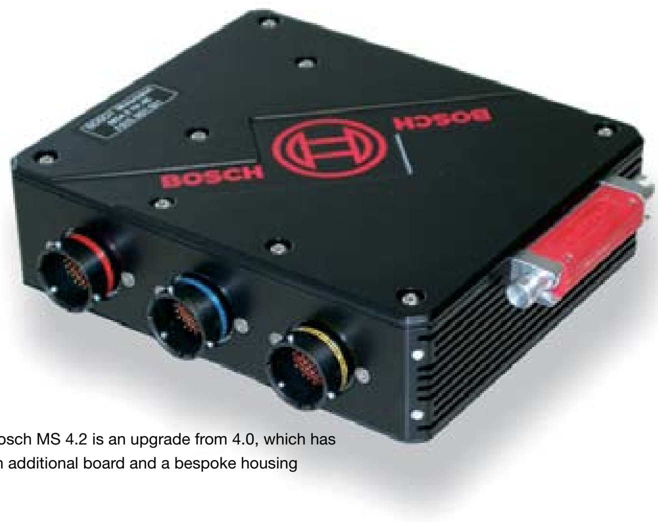
"Having its own bespoke software, MS 4.3 can run ten cylinders to 20,000 rpm"

The MS 4 series is founded on proven production hardware, which is described as 'bulletproof'. It has been designed to provide very capable yet cost-effective competition engine management systems.

The MS 4.0 unit has eight ignition drivers for external power stages (which means that the switching is done at an individual external coil under the control of the ecu) and eight independent injection stages (which means that the switching is done within the unit). Knock (vibration) and lambda sensors are supported for knock and closed loop control and various engine parameters can be measured with different input channels and transferred via CAN interface to an optional flash card data logger.

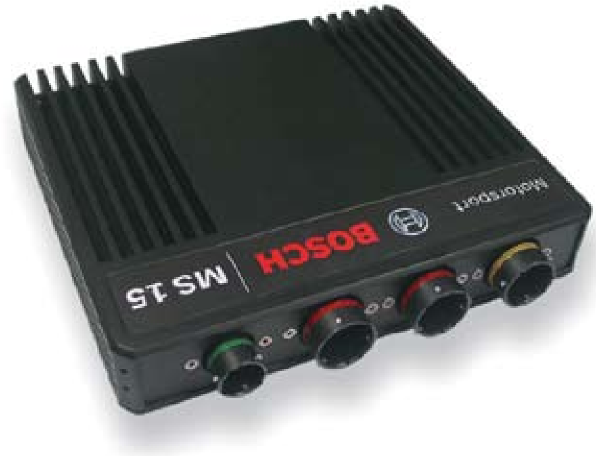
Motronic MS 4.2 is an upgrade from MS 4.0 with an additional board to provide for another eight injector drivers. It has its own housing, which accommodates not only the additional board but also an integral data logger. The latest MS 4 unit, which Grand Am will use, is MS 4.3. This accommodates 10 ignition and 10 injector drivers. It has Mil-Spec rather than production connectors and this change permitted the addition of four power stages over MS 4.0 without the need for an additional board. Using the architecture of the production board in this alternative way and forgoing an integral data logger means that MS 4.3's bespoke housing can be smaller and lighter than that of MS 4.2.

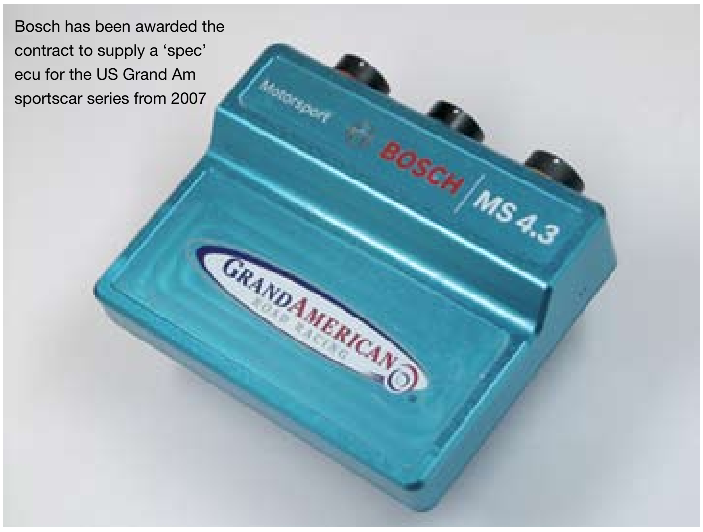
Where MS 4.0 supports eight analogue channels, MS 4.3 has an additional integrated circuit that allows it to support 16, with flexible configuration. In MS 4.3 the production ME 7.1 micro-controller is replaced to attain more computing power. Unlike the production unit it has internal flash, which ensures that it can immediately fetch an instruction. Compared to MS 4.0 it has over 50% more computing power and it is significantly faster.



Bosch MS 4.2 is an upgrade from 4.0, which has an additional board and a bespoke housing

Bosch offers a 'mid range' system for the increasing number of competition cars exploiting compression-ignition





Bosch has been awarded the contract to supply a 'spec' ecu for the US Grand Am sportscar series from 2007

Having its own bespoke software, MS 4.3 can run ten cylinders to 20,000 rpm. However its production base limits it to 12 analogue inputs whereas typically an LMP1 engine would call for something in the region of 80.

Compared to MS 4.2, MS 4.3 features higher computing power, more ignition power stages (10 versus eight), more sensor inputs and a more compact housing, with Mil-Spec connectors. While it can drive a V10 engine with one injector per cylinder, MS 4.2 can drive a V8 with two injectors per cylinder. These days most engines run just one per cylinder. The lack of an integral data logger is likewise not seen as a drawback – an external data logger can be fitted elsewhere on the car, where it is more easily accessible for downloads.

MS 4.3 was developed initially as the spec Grand Am ecu for 2007 onwards. "In accommodating Grand Am's requirements we saw the opportunity to improve upon MS 4.0", remarks Bosch Motorsport hardware development specialist Alexander Leuze. "One such improvement was to introduce Mil-Spec connectors rather than rely on production connectors – these connectors are plugged and unplugged much more frequently in the racing than in the road car environment."

Leuze explains that, in essence, in MS 4.3 the production circuitry is used electronically but not mechanically, as it is in MS 4.0. Whereas MS 4.0 is pure production hardware, as we have noted MS 4.3 has its own board, a modified layout and some new parts.

Comparing MS 4.3 with MS 4.0 in detail, we find that it weighs 750 g as opposed to 430 g but that it measures slightly less in plan area (150 x 160 mm compared to 180 x 162 mm). It is also slightly slimmer, its connector end height 40 mm and its main body height ▶

PRODUCT TESTING AT BOSCH MOTORSPORT

Bosch Motorsport has a test room in which it is possible to run an engine management system as if in a race. A test rig simulates the data that the car would supply to the ecu under race conditions, using as the basis for this actual data taken from a data logger. The ecu then provides the actual output signals that would be used to manage the engine.

Bosch Motorsport has a test rig that carries all of a racecar's electrical items, including such as its head and tail lights. The engine management system includes the injectors, which it can switch on and off as if running the engine. However, it is not feasible to carry out an endurance test in this manner as the injectors would soon overheat in the absence of fuel.

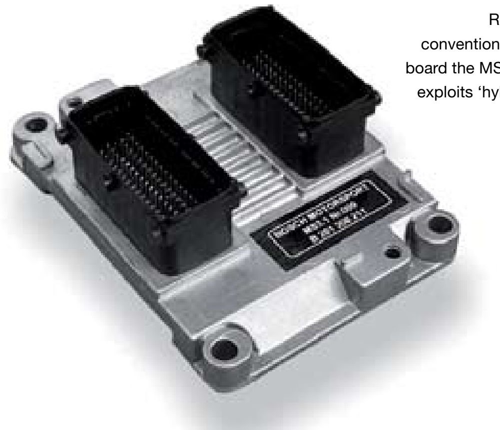
In another test room the company has a 'shaker table' rig, which subjects an engine control or dash display unit through various accelerations and vibrations. It can be run using data acquired on track, so as to simulate real life forces. A flash lamp can be used to reveal the movement of parts within the unit on test.

27 mm compared to a consistent height of 46 mm for MS 4.0. So MS 4.3 is more compact but heavier, the additional weight reflecting its increased functionality, its bespoke dust and waterproofed housing and its three high pin density Mil-Spec connectors.

Where MS 4.0 has a simple production sheet metal housing that of MS 4.3 is a more substantial production in aluminium. Both MS 4.0 and MS 4.3 feature a vibration dampened circuit board. MS 4.3's three Mil-spec connectors provide 165 pins, each individually filtered, whereas MS 4.0's production connectors offer 121 pins, again individually filtered.

In terms of functionality, as we have noted MS 4.3 has ten ignition drivers for external power stages where MS 4.0 has eight and it has ten independent injection power stages where MS 4.0 again has eight. On top of that, MS 4.3 has the potential for asymmetric ignition and injection timing, which means that it can cope with uneven fire. Unlike MS 4.0, MS 4.3 supports 60-2 and 36-2 ignition trigger wheels.

MS 4.3 has 21 power stages for additional controls such as fuel pump, brake light, malfunction lamps on the dash and so forth. MS 4.0 has 20 such stages. Both systems support traction control and have turbo functionality. Both have two independent wide range lambda circuits, which allow for lambda closed loop engine control. Both systems also have knock control, MS 4.3 having four inputs for vibration knock sensors where MS 4.0 has two.



Rather than use a conventional printed circuit board the MS 3.1 control unit exploits 'hybrid' technology

Both systems support drive-by-wire, having a H-bridge output. In terms of communication interfaces, both MS 4.0 and MS 4.3 have a K-line serial interface and two CAN interfaces for external communication.

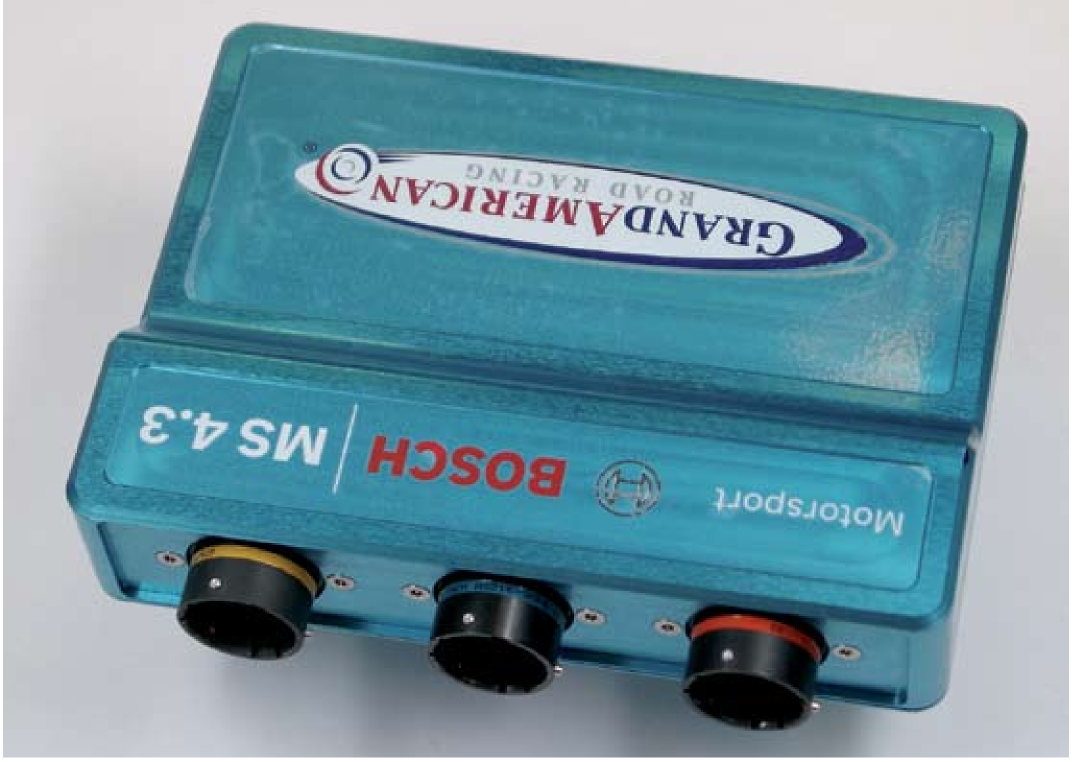
MS 4.3 is essentially a modification of a production unit so as to optimise it for motorsport applications. Its production base helps ensure reliability and keeps it affordable. Leuze explains that the actual version of MS 4.3 supplied to Grand Am competitors will have a few features specific to that application.

For example, there is a special interface under development to allow the Grand Am scrutineers to connect to the unit to see what software is running and what is enabled and what disabled. There will also be a special tool required to enable traction control, so that the individual customer cannot enable it without the organiser's permission.

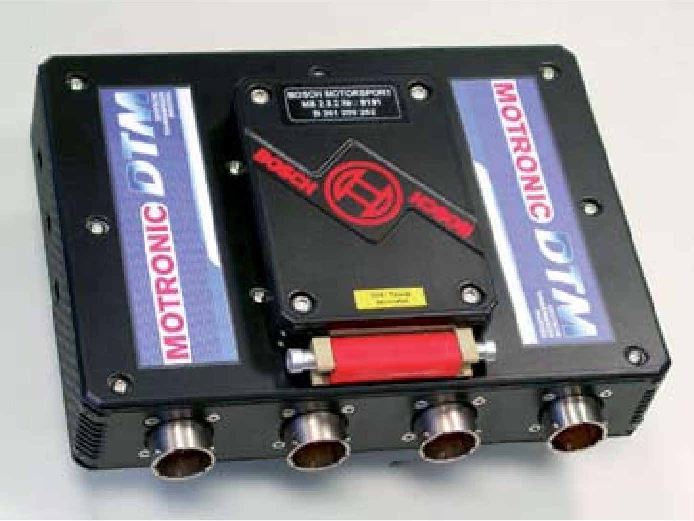
HIGH END GASOLINE ENGINE CONTROL

Hybrid technology is at the cutting edge of engine management system technology in the production car world but there are drawbacks that limit its application in racing. A hybrid circuit is an electronic circuit consisting of several different levels of components, including printed circuits, semiconductors, resistors, capacitors and so forth, all encapsulated in epoxy. Compared to a conventional pcb a hybrid circuit is very small and robust with good resistance to shock and temperature.

The Grand Am series will use a version of the powerful new Bosch MS 4.3 engine control unit



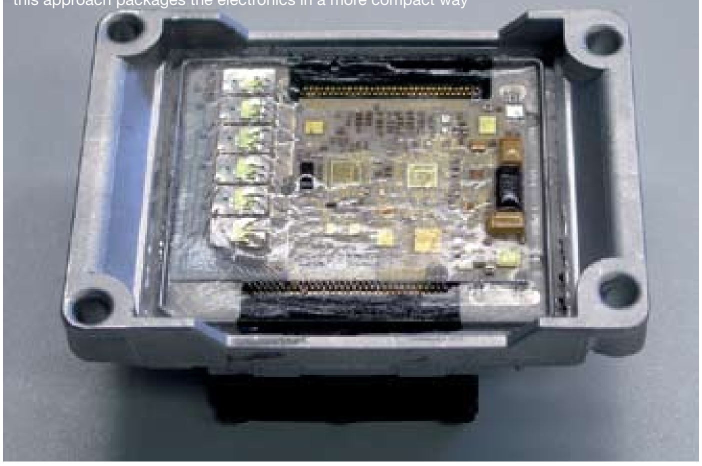
Bosch supplies engine control units to both of the current DTM championship contenders, Audi and Mercedes

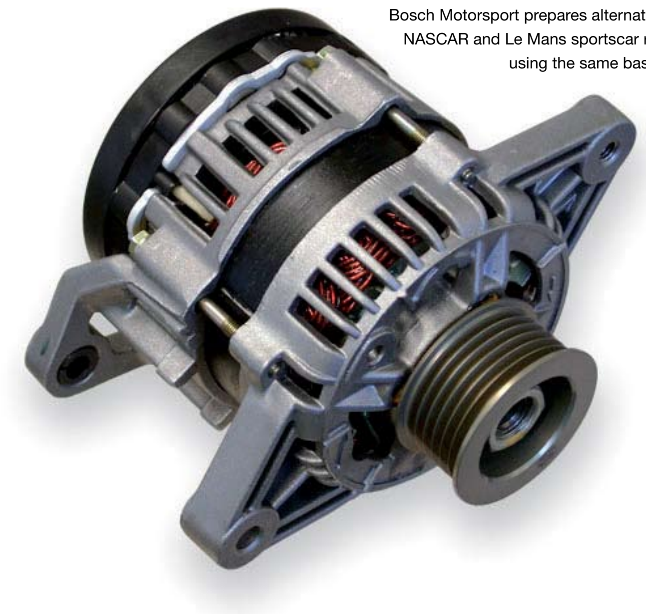


In the production car world, hybrid technology has enabled Bosch to make engine control units that are smaller and lighter with a higher level of reliability. However, to produce a dedicated hybrid unit for motorsport would be an extremely expensive exercise and the market simply isn't big enough to absorb the development cost. On top of that, once put into production the hardware cannot be modified so the system would lack the flexibility that many motorsport customers require, particularly at the higher end.

In view of this Bosch Motorsport is looking at ways that it can beneficially adapt hybrid technology from production. The first step was the Bosch MS 3 series of engine control units. This is essentially production hybrid hardware with software appropriate to motorsport applications. MS 3.1 will run a six cylinder competition engine, 3.3 an eight cylinder, while 3.4 has been devised for high revving motorcycle engines. Users who do not need a high level of flexibility can benefit from that fact that these systems, based around a tiny micro-controller are beneficially light, compact and robust.

To further exploit hybrid technology Bosch Motorsport is developing a combination of hybrid and pcb technology. It is putting hybrid technology into a conventional board, so as to gain the flexibility that higher-level users require. In the first such combination ecu the micro-controller is conventional and so are the peripheral circuits, while the power stages are hybrid circuits.


The hybrid heart of Bosch MS 3.1 – this approach packages the electronics in a more compact way


Bosch Motorsport prepares alternators for NASCAR and Le Mans sportscar racing, using the same basic unit

BOSCH RACING ALTERNATORS

At Bosch Motorsport production-type alternators are assembled by hand for motorsport applications. Skilled personnel elsewhere in the company hand-wind these items more tightly than normal and the manual assembly at Bosch Motorsport ensures the best possible balance of the rotating assembly.

The Bosch alternator used widely in NASCAR competition is the GCM. Compared to a production model this hand-built unit has a copper rather than aluminium rectifier base in view of the level of heat to which the unit is subject when the engine is switched off. It also has a special aluminium shield for the regulator.

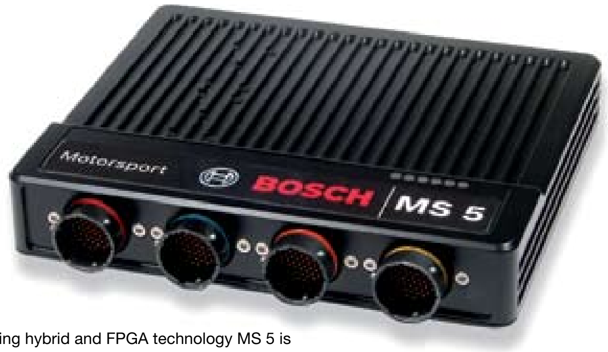
The GCM is designed to be belt driven, located in the vee of the engine by a mount on each side of it. Weighing 3.2 kg, it produces 140 amps at 14.5 volts.

For Le Mans cars Bosch makes the GMCI version of its racing alternator. This is very similar to the NASCAR production but it has a slightly different bearing housing. In the case of the Audi R10 the housing is a magnesium production, which saves some 100 gm.

Power stages are switching devices and electrical switching causes heat (electrical loss). A hybrid power stage takes up less space, weighs less, offers superior mechanical shock resistance and superior thermal characteristics. A conventional power stage can safely run up to 75 degrees Centigrade whereas a hybrid power stage can sustain as much as 120 degrees without failure.

This level of heat resistance means, for example, that a customer can mount a full hybrid ecu on the engine without risk of failure due to excessive temperature. In the case of the combination technology unit, there is still a limit of 75 degrees due to the use of a conventional micro-controller. However, there is an advantage here in that the hybrid power stages will run cooler, which means that less heat is generated through power switching within the ecu.

The benefit of cooler running power stages is twofold. The fact that the ecu generates less heat internally means that it can operate successfully in a hotter environment. At the same time, the higher the rpm of the engine, the higher the switching temperature: using hybrid power stages increases engine speed control capability. ▶



Exploiting hybrid and FPGA technology MS 5 is the foundation of future Bosch racing systems

The first combination hybrid/pcb ecu from Bosch Motorsport is MS 5.0, which has been designed for a high-end gasoline indirect injection system. Still at the prototype stage, it is under development as the replacement for Bosch Motorsport's existing MS 1.10 and 2.9 high-end ecus, as used, for example, in LMP1 gasoline engines.

MS 1.10 and 2.9 use multiple micro-controllers. MS 5.0 has comparable computing capability from a single micro-controller. MS 5.0 features a newly developed micro-controller, which has a speed of 400 MHz – some ten times faster than that used in the MS 4.0 series. It exploits floating rather than fixed-point technology, for faster calculations.

Measured in terms of Machine Instructions Per Second (MIPS) the performance of MS 5.0 is inferior to that of MS 1.10 and 2.9. However, the fact is that those units use four controllers all of which need the same data. This causes a data synchronisation issue, which takes computing power. So much so that the single micro controller in MS 5.0, although capable of less MIPS than the multiples, offers greater effective computing power.

Along with hybrid circuits, MS 5.0 exploits Field-programmable gate array (FPGA) technology, another pioneering step. An FPGA is a semiconductor device containing programmable logic components and programmable interconnects. These components can be programmed after the device has been manufactured, by the designer and even by the end user, so that the device can perform whatever logical function is required of it.

Bosch refers to the FPGA as 'programmable hardware'. In a regular ecu the micro-controller interfaces directly with the likes of analogue/digital converters, sensor processors, CAN inputs and so forth. In the case of the FPGA, this device sits between the micro-controller and its interfaces (it is linked to it by a high speed bus). It can be programmed to accept different types of input, according to user requirement.

If a user wants to switch from CAN to Ethernet, for example, in the case of a conventional ecu this would call for a replacement board. Using the FPGA, instead of changing a board, the description of a given module within the FPGA can be changed. Thus a switch from CAN to Ethernet is possible without hardware alteration, simply via software - hence 'programmable hardware'.

Clearly the FPGA offers a lot of additional flexibility. How many modules a given FPGA can accept is a function of its capacity and

"It exploits floating rather than fixed-point technology, for faster calculations"

of how that capacity is used – different types of functionality take up different levels of module capacity. Unsurprisingly, Leuze reports that Bosch Motorsport is exploiting an FPGA the capacity of which is adequate for the anticipated needs of MS 5.0 as a high-end system…

Development of MS 5.0 is proceeding with the aid of MatLab Simulink, which provides for very fast software development. This software package can simulate each function of the ecu on a normal PC. Instead of programming the ecu in 'C++' in the usual manner, each function is drawn in MatLab and the software tested in the PC as if it was operating within the actual ecu. For example, Lambda control software can be written and tested on the PC before it is downloaded to the ecu. Once it is validated it can be sent across at the click of a key via Ethernet cable.

Technologically Motronic MS 5.0 is more advanced than the high end diesel engine control systems that Bosch is developing for Le Mans racing. However, Leuze points out that there is less benefit from the application of hybrid technology for the diesel ecu.

MS 5.0 is under development as the platform for all subsequent Bosch racing systems, including ones exploiting high pressure injection. Bosch indirect gasoline injection systems normally operate at a fuel pressure in the region of 5-10 bar. Meanwhile the Seat direct gasoline injection system developed by Bosch Motorsport operates at 120 bar and the Audi direct diesel injection system works at something well in excess of 1600 bar.

In Formula One in recent years there has been experimentation with high pressure indirect injection. Bosch has supplied the injectors for a 200 bar system, which is now banned by a ruling that caps pressure at 100 bar. MS 5.0 has alternative power stages, which operate a 12-volt electro-magnetic injector that can handle 120 bar, whereas in the past such high pressure injectors typically needed 90 volts. In fact, a 200 bar version of this 12-volt injector is now available, as the potential of high pressure indirect injection is explored outside of Formula One. Future development is expected to include a piezo-type injector suitable for use with gasoline. ■

BOSCH MOTORSPORT CONTACT DETAILS

Bosch Motorsport
An der Bracke 9, 71706 Markgroeningen, Germany

Tel. +49 (0) 711/811-3981
Email: motorsport@bosch.com
www.bosch-motorsport.com