Development of Electronic Control System for Formula One

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ABSTRACT

The application of electronic control systems has been rapidly increasing in Formula One cars as well as in other vehicles. System performance is a crucial element in conducting precision control and measurement of cars.

Starting with the 2006 season, the Honda works has been working to apply original Honda systems not only in the engine control system, as before, but in all vehicle electronic control systems.

In order to pursue higher performance at the same time as enhanced in-vehicle mountability in Formula One electronic control systems, it is necessary to carry out optimization of these systems together with thoroughgoing miniaturization. On-board systems have an electronic control unit (ECU) with integrated functionality linked by a high-speed network with units located in every part of the vehicle. High-speed telemetry is used to coordinate these with the garage system in order to optimize systems.

The enhancement of unit performance by means of higher speed and greater precision contributes to heightened controllability, and particularly to enhanced precision of driving force control and gearbox control. High-speed communication also contributes to greater measurement performance in the pit.

1. Introduction

Formula One cars in recent years have incorporated more than just the engine control and gearbox control found previously. From mid-2001 to the 2007 seasons, traction control and engine brake control have come to be allowed in the regulations. Clutch control was not prohibited up until 2007.

Traction control and gearbox control, in particular, require precisely coordinated control of the engine and chassis in real time. This has required advanced computational capability and measurement performance. Furthermore, Formula One cars demand aerodynamic performance, so that there are limited on-board installation locations for electronic control units in Formula One cars. This means that systems require greater compactness and lighter weight.

The functions of electronic control systems for Formula One are generally for two purposes, for driving and for analysis. In order to achieve compactness and light weight, the latter functions are assigned as much as possible to pit systems. In this way the former functions can be optimized, and this was the basic conceptual approach to the construction of these systems.

This article will provide an overview of Honda Formula One electronic control systems, introduce the issues involved in development of the systems, and describe the contents of the development.

2. System History

Figure 1 shows the history of electronic control systems for the third era of Honda Formula One. Development of third-era Formula One systems began in 1998 with a view to applying integrated engine and chassis systems to racing.

Under the BAR-Honda system from 2000 to 2005, engine control systems were supplied to the team. From 2006, when Honda works joined in the competition, the Honda full system was provided as a chassis integrated

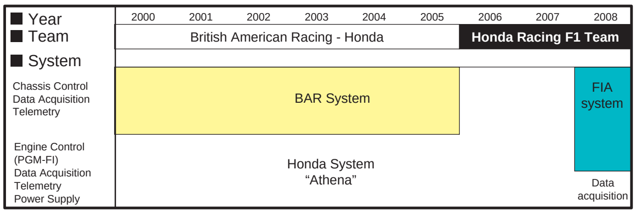

Fig. 1 History of Honda Formula One system

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management system. The system was named Athena after the Greek goddess of wisdom and victory.

In 2008, it was made mandatory to apply International Automobile Federation (FIA) standard systems. The purpose was to standardize engine and chassis control and to reduce costs. As a result, Honda's in-house developed systems that were used in racing were limited to the devices for engine use, sensors, and data logging systems.

3. Configuration of Electronic Control Systems (Athena)

3.1. Optimization of System Configuration (Functional Integration and Distribution)

A car's aerodynamic performance, which determines its body design, makes a very important contribution to lap times. In order not to place constraints on the freedom of the design, it is necessary to have system configurations that are compact and have outstanding mountability.

The main locations for mounting electronic unit were, as shown in Fig. 2, beneath the radiator ducts on either side of the chassis. The only other locations were near the throttle pedal toward the front of the car and inside the cockpit. The systems were therefore mounted in a distributed configuration and were linked by a high-speed network in order to achieve a balance of mountability and functionality.

Figure 3 shows the system configuration. The network in the chassis is centered on the ECU and ties together the various units, sharing sensor data and fail data to operate the systems. The ECU has the functionality for integrated control of the engine, chassis, and measurement. It acquires all information from the chassis and conducts the operation of every device as well as the processing of measurements. Each unit that has been distributed can manage the measurement and control functions for the different applications, and is connected to the network as necessary. Of these, the Front Data Acquisition (FDA) unit acquires data from numerous sensors at the front of the chassis. Since it processes signals used for real time control computations, it is connected with the ECU by high-speed communications at 10 Mbps.

In the pit, the client PC and the ECU are connected

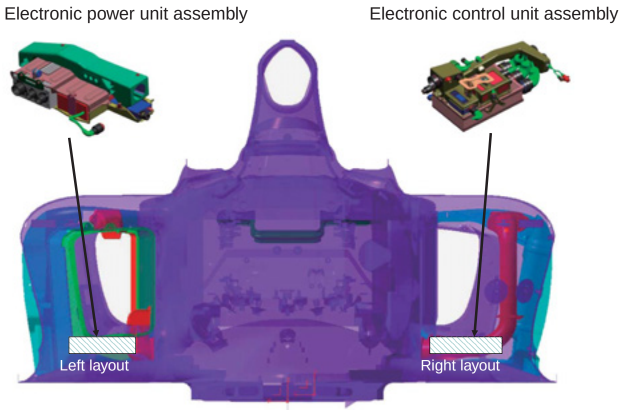

Fig. 2 Electronic unit layout (front view)

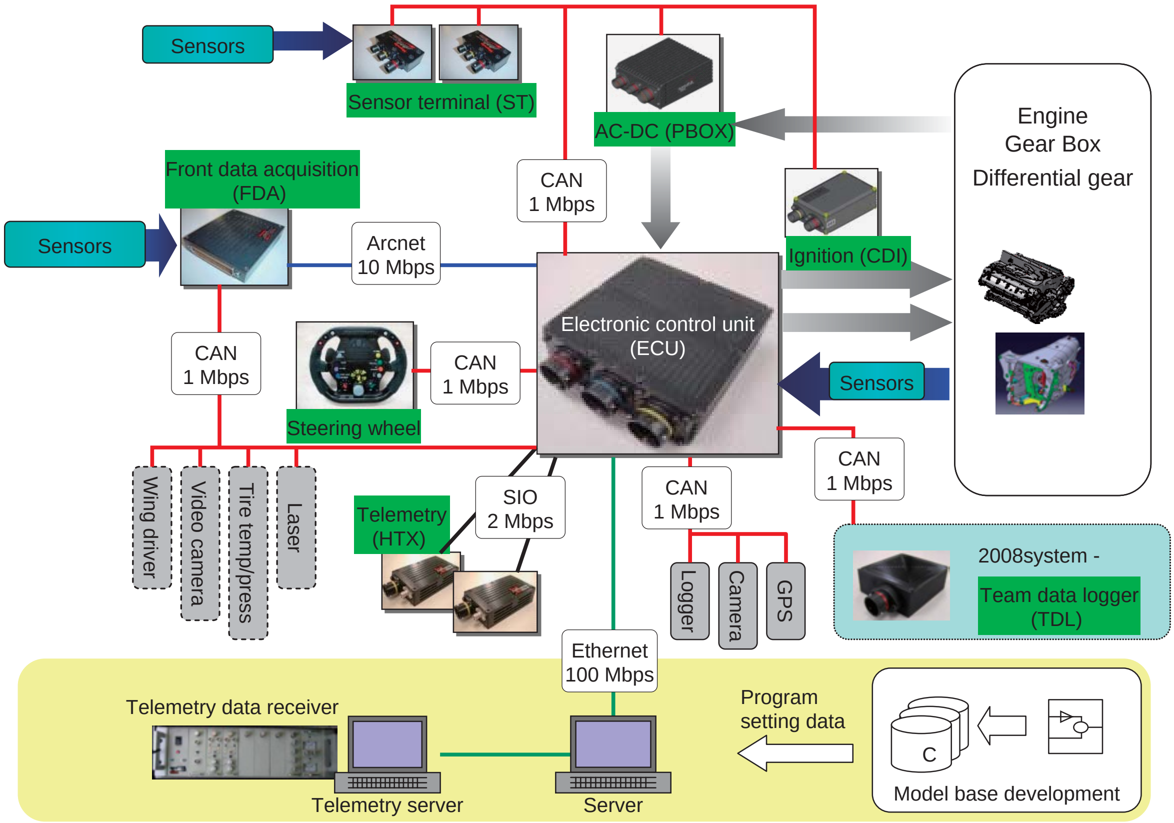

Fig. 3 Athena system

by Ethernet communications (100 Mbps) so that logging data and other high-volume data can be received in a short time. All vehicle checking applications that handle high volumes of data are also placed on the client PC side in order to simplify on-board systems.

3.2. Explanation of Each Component

(1) ECU

The ECU has three roles, in engine control, chassis control, and measurement control. In engine, it controls the ignition timing, volume of fuel injected, and throttle opening, and realizes the requested torque. In chassis control, it uses vehicle behavior information to perform wheel drive torque transfer control and seamless shift control computation for gear shifting. In measurement control, it performs measurement computation of two kinds, in telemetry and data logging.

(2) Capacitive Discharge Ignition (CDI)

The CDI is the unit that supplies the energy for ignition to the engine ignition coil. The CDI method provides greater real time effectiveness than the full transistor method and greater precision in drive torque control (traction control and engine brake control) and engine speed control. This unit also simultaneously has misfiring detection functionality by means of ion current detection.

(3) Power Box (PBOX)

The PBOX is the unit that operates as the voltage regulator and power distributor (sequencer function). The voltage regulator part uses a highly efficient converter method and supplies two power outputs (14 V and 7 V) so that the power components where this power is supplied can be made more compact.

(4) Batteries

The system uses NiMH batteries for compactness and lighter weight. Battery temperature monitoring and charge control are handled by the PBOX.

(5) Telemetry transmitter and receiver (HTX, HRX)

The HTX is the data transmitter unit by which data processed by the ECU is sent by radio to the pit. The HRX is the data receiver unit that receives radio data.

(6) Front Data Acquisition (FDA)

The FDA is the unit that acquires data from sensors at the front of the chassis. It is equipped with input/output (I/O) capable of multi-channel analog input. This functions to process acquired analog signals by filtering computations and then transmits them to the ECU by high speed communications (10 Mbps).

(7) Sensor Terminal (ST)

The ST is a compact sensor measurement unit used for measurement of the environment in the chassis and in the engine. Up to eight ST units can be connected to the ECU and CAN communication lines.

(8) FIA/FOM units

The FIA/FOM units include a data logger, camera, and GPS units. Installation of these units is required by the Fédération Internationale de l'Automobile (FIA), the umbrella organization for automotive matters, and by the Formula One Management (FOM), the organization that conducts racing. Car data from the ECU is sent to the units by CAN communications, and the racing circuit data for each team is managed and used by the FIA and FOM.

(9) Team Data Logger (TDL)

The TDL unit has a logging function and reads data from all types of sensors. The use of FIA standard systems has been a requirement since 2008. This unit is therefore developed so that assistance tool used up to 2007 can continue to be used. The TDL is connected with FIA standard systems by CAN communications.

(10) Garage system

The garage system is system infrastructure composed of the server installed in the pit and the client PCs used by each engineer. It was designed exclusively for use in Formula One racing. As for the communication between the car and PC, Ethernet was used.

3.3. High-Speed, High-Precision Control (Engine, Chassis, and Measurement Control)

The ECU was required to have high computational capability in order to provide satisfactory control performance and measurement performance. In the third era of Formula One, the main items for control development have been drive torque control and seamless shift control. The efficiency of this control development was enhanced by the introduction of model base development using floating point operations. Figure 4 shows the controls that were applied, together with the changes in computational capability. The regulations made driver assistance control (slip control, typified by traction control) permissible in mid-2001. From then up to 2007, when it was outlawed, this demanded the greatest computational capability. This also involved an increase in the volume of data for control analysis, and the CPU and data transfer speeds were increased in order to be able to support the demand for high-speed sampling and logging on multiple channels for measurement function.

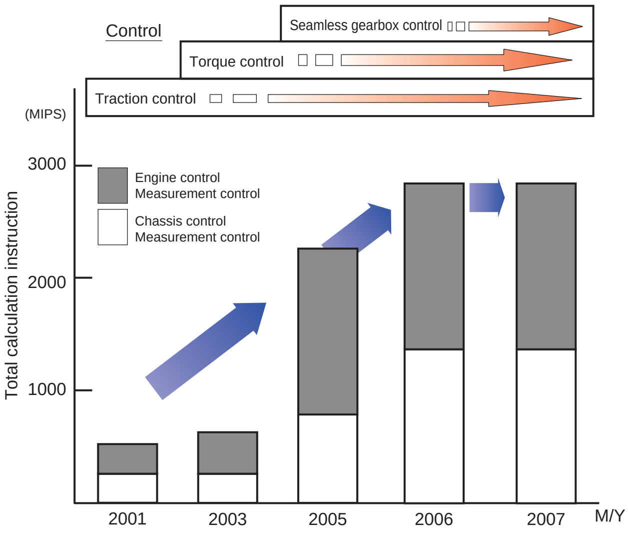

Fig. 4 Processing speed increase

3.4. On-Board Layout

The main electronic control units were placed beneath the radiator duct. This location was at the center of the chassis as a whole, as well as at a low position, and it was the largest area where units could be mounted without affecting the vehicle dynamics. As shown in Fig. 5, the ECU and CDI are placed on the left side of the chassis between the radiator duct and the under floor. They are affixed to carbon fiber brackets on anti-vibration mounts. As shown in Fig. 6, the PBOX, battery, and HTX are placed on the right side between the radiator duct and the under floor, like the units on the left side. In order to cool the units, a duct shape capable of introducing the necessary cooling airstream was simulated (Fig. 7), and on that basis a duct shape that would have minimum effect on the aerodynamics was created. This meant that the heat radiation structure of the electronic control units was crucial.

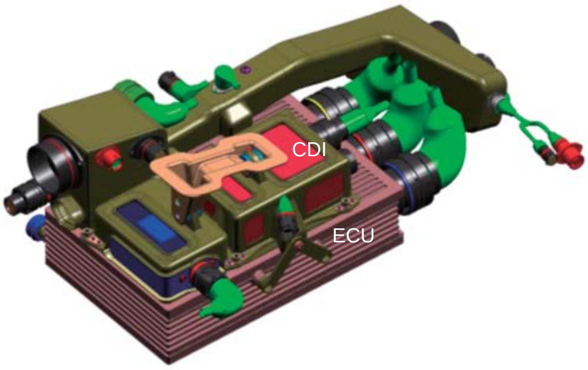

Fig. 5 Left side electronic units

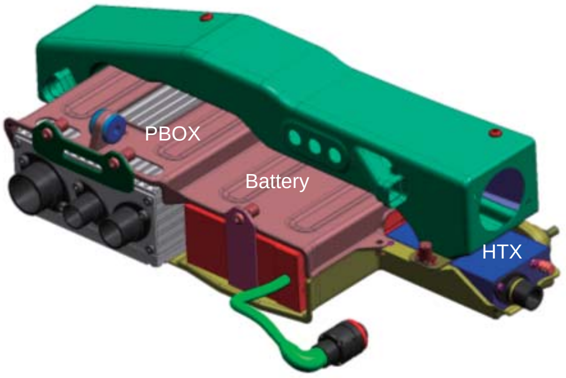

Fig. 6 Right side electronic units

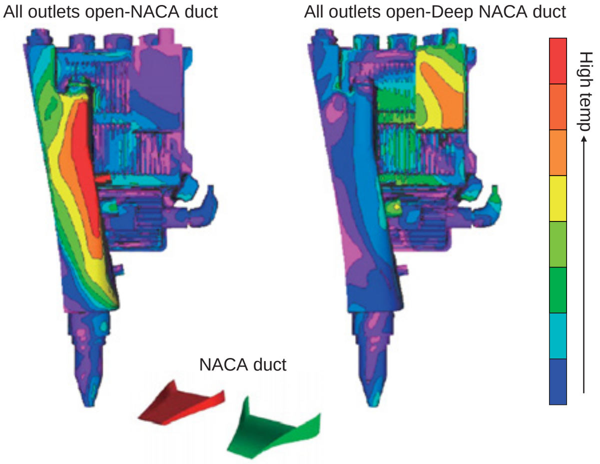

Fig. 7 Cooling duct simulation

4. ECU Architecture and Functions

4.1. ECU Hardware Architecture

In order to realize the performance requirements for the electronic control systems described at the start of this article, the hardware performance of the ECU in particular was important. An architecture with multiple CPUs optimally suited to the various functions carried out by the ECU was created. The memory architecture that coordinates those CPUs and their communications links are described below.

The basic architecture of the ECU, as shown in Fig. 8, includes three CPUs: the Application CPU (ACPU), the Device CPU (DCPU), and the Gateway CPU (GCPU). The ECU was configured in two blocks, one for the engine and the other for the chassis, and their I/O were configured for their respective input and output devices.

A balance between real time operation of the devices and high-speed computational processing of applications was sought by distributing functions so that processing would not be concentrated in a single CPU. In the part for device operation, operations of the injector and the ignition device take place at 150 μs intervals when the engine is running at high speed. Consequently, these were made into functions handling only device I/O operations, and were separated from the processing of applications that require high throughput computation. The selection of a dedicated automotive CPU (DCPU) with better I/O functionality therefore satisfied the functionality requirement.

A high-speed processing CPU (ACPU) was selected to handle the control applications used with the engine and the chassis. What had until then been controlled using three automotive microcomputers was combined into one. This reduced the need for data access between CPUs for applications and reduced unnecessary processing.

The CPU used for measurement control carries out high-volume data communications with PCs and communications with telemetry units. A CPU (GCPU) that is high-speed and is equipped with many varied communication devices was therefore selected, allowing data operations that make use of high-speed serial and Ethernet communications.

The multiple CPUs with distributed functions have to look up each other's data. For example, data that is necessary for telemetry and logging is sent to the GCPU and the device instruction values that are output by control computation are sent to the DCPU. The calibration data and commands that are sent from client PCs in the garage system are shared by every CPU. In order to implement these actions, DPRAM was placed between all the CPUs and high-speed synchronized access was enabled by means of trigger signals when they make connections.

Local memory is assigned to each CPU according to the functions that are required. Memory functions include flash memory for program saving, SDRAM for program execution, NVRAM for data backup, and Compact Flash (CF) memory for use in high-volume logging. CF memory is installed with two cards in parallel in order to expand the data bus width from 16 bits to 32 bits. The purpose was to achieve higher-speed data processing and access processing during logging.

The engine and chassis blocks are connected by ARCNET communications at 10 Mbps. This is to transfer the parameters required for coordinated control above 1 kHz process cycle rate.

Up to 2008, the GCPU performed logging data retrieval processing and data download processing in alternation. How to conduct these processes simultaneously, therefore, became the technical issue when a balance between increased logging volume and reduced download time was sought.

The high-speed memory controller shown in Fig. 9 was therefore developed. The logging data retrieval process and download process could be conducted in parallel by using the PCI bus and the CPU local bus. The increased speed and greater volume in reading and writing logging data was realized by means of a circuit architecture with multiple SD memories connected in parallel. This memory controller was installed in the TDL developed for the 2009 model, and it achieved a 30% increase in data download speed together with an increase in capacity (to a maximum of 8 GB).

4.2. ECU Software Architecture

The ECU software can be generally divided into these main parts: the engine control part that handles control of engine ignition and throttle, the part that handles control of the gearbox and vehicle behavior, and the data measurement part that handles the recording of circuit data and its transmission to the garage system.

A real time operating system was implemented on each CPU. This met the demand for the advanced real time performance needed to realize high-speed control computations, sensing, and communications. As shown in Fig. 10, the software is divided into three distinct and independent layers, namely, the OS layer, the middle layer that performs communications and I/O control, and the application layer that performs control computations.

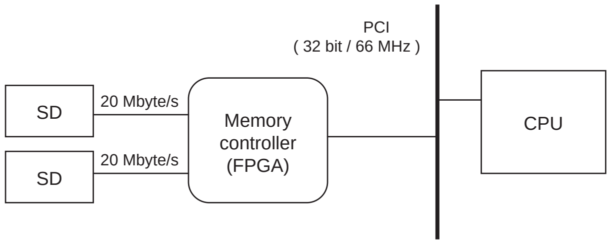

Fig. 9 SD memory controller

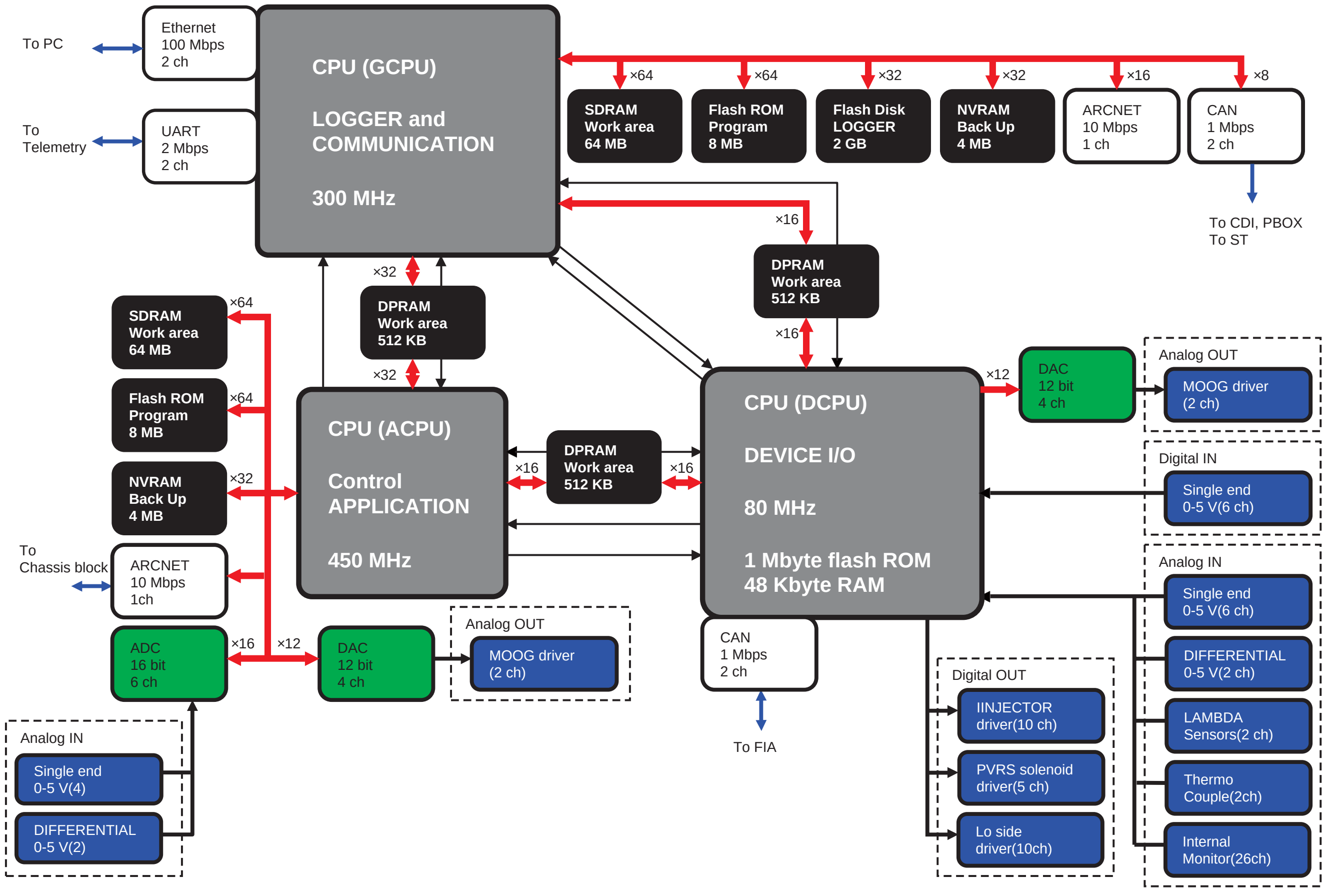

Fig. 8 Hardware architecture

In order to enable independent control development by application users in model base development, a development environment capable of automatically generating execute files was set up and control development efficiency was increased (Fig. 10).

4.3. Circuit Data Measurement Function (Logging)

The logging function is used to make settings in the chassis and power train, to monitor conditions, and to conduct simulations. It therefore needs to provide accurate data and handle large volumes of data. This required specifications that include 2000 channels and sampling rates from 10 kHz to 1 Hz.

For the efficiency of circuit tests, it is important for the engineers to be able to quickly determine conditions in the vehicle after it has been driven, and make it ready for the next driving session. It was necessary, therefore, to shorter the time from data download to data display, and to provide techniques for easy analysis.

Logging data is accumulated each time the car is driven. This is used not only on the circuit, but also for analysis and simulation at the various development centers. It was necessary, therefore, to associate the circuit data and the test items.

4.3.1. Measurement data format

In order to facilitate data management in every driving situation, data measurement using the logging system was set up to split off the data from each driving session and write it to the logging memory (Fig. 11). A single driving data is composed of the Run Header and the Run Data.

The Run Header area records the Lap Data, which is updated on every lap; the Straight End Data, which gives the highest speed point at the ends of straightaways; and the Fail/Warning Data, which gives information on malfunctions. These were arranged to enable engineers to readily identify characteristic points in each lap. Index data for logging-related data is also recorded so that circuit data, calibration data, and the like can be tied together and accurate data management can be conducted after driving sessions.

The Run Data area contains records for every channel subject to logging.

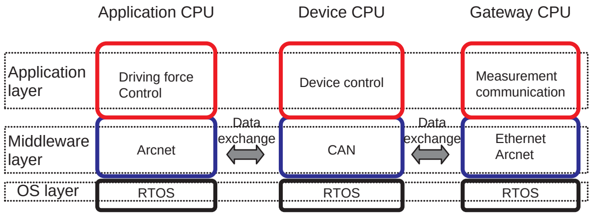

Fig. 10 Software architecture

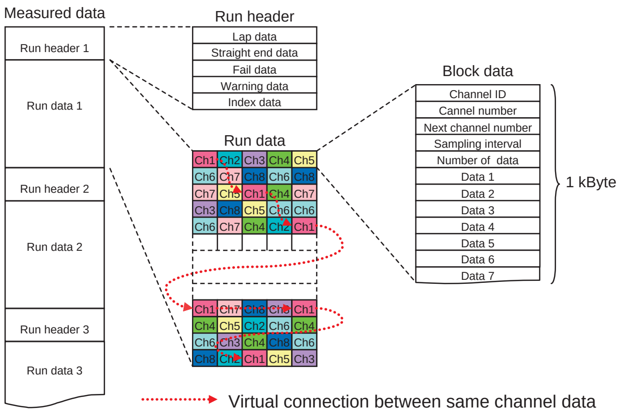

Fig. 11 Logging data format

4.3.2. Data recording techniques

As explained earlier, it is necessary for data logging to record data from measurements conducted at a high sampling rate. Data logging with a high sampling rate involves increased amounts of data, which leads to increased download times, and this ultimately diminishes the efficiency of circuit tests. For this reason, a trigger logging function was developed. Under specific circumstances, such as when a gear change is performed, when a malfunction occurs, or when some other condition necessitating acquisition of detailed data at a certain rate occurs, past data is recorded at a high sampling rate for a maximum of one second back from a trigger point. At other times, data is recorded at a low rate so that the volume of logging data can be reduced.

The trigger conditions are defined on a client PC in the C language and written into the logging configuration file using reverse Polish notation. After the ECU has decoded the trigger conditions, it implements trigger processing when those conditions are met. The system was set up to allow the configuration to be changed according to test circumstances.

When initially developed, sampled data was simply put in time series and the data on each channel was recorded in logging memory using a discontinuous method. Since the aim of this was to reduce the processing burden on the ECU. However, when CPU performance was enhanced, the volume of logging data increased and the issue of the time required to display a graph occurred.

The use of a high-speed CPU (GCPU) enabled the data recording format to be changed so that the data in each channel are in continuous sequence and this upgraded the drawing speed. The data recording format was changed so that the measurement data for each sampling from the same channel is placed in a single block with a fixed length of 1 kB, and measurement data is recorded as an aggregation of blocks. (Figure 11 shows data from the same channel in blocks of the same color in the middle column.)

With this change in format, the block of the same channel is read by unit and taken united, so an increase in graph display speed was achieved as a result.

This logged data can not only be displayed in analysis tools, it can also be input to Hardware In the Loop Simulation (HILS) and used to reproduce driving conditions on a PC. It has also been used to feedback measures to solve circuit-running issues.

4.4. Garage System Functions

The purpose of the garage system was to manage circuit data, provide race strategy support, and assist in conducting vehicle checks. The functions that are important in running the car were built into the ECU. Other additional functions for support purposes were to be taken on by the garage system. This was the conceptual approach in development, and it was tied-in with miniaturization of the ECU (Fig. 12).

In the pit, the car is connected to the garage network where such actions as logging data capture by client PCs and transfer of calibration data take place. The logging data is stored on the garage system server so that the data can be looked up by multiple client PCs. It is also given numerous functions for support of racing strategy and test runs, and the system was set up to allow operational commands to be issued to an ECU that is connected to the network. Typical support functions and their association with the ECU are described below.

(1) Data setting support function

At the actual race location, engineers change the engine and chassis settings on the basis of circuit data. Changes to settings are made frequently, and such changes need to be made up to the point immediately before a race begins. Therefore, the system was set up so that the data transmitted from client PCs to the ECU would be the only data changed by engineers on client PCs, enabling instant setting changes.

(2) Auto Warm-up

Performance enhancements in the engine and gearbox have brought increased complexity in engine starting and warm-up as well as the engine checking mode. Auto warm-up is a support function that automates these activities. This check mode includes numerous check modes for determining the engine status, and the engine is controlled using control instruction values sent from a PC. The ECU is not prepared beforehand with a profile of these check modes. Instead, the system specification calls for the profile to be stored in the form of files on client PCs in the garage system. This allows the creation of a variety of check modes adapted to engine specifications and environment of use without changing the ECU software.

(3) Configuration of Steering Wheel Functions

In addition to driving operation, the steering wheel has the capability for the driver to check or make changes to settings and car information while driving, in accordance with racing strategy and changes in the circuit environment. Figure 13 shows how the steering wheel is equipped with multiple switches, buttons, and an LCD display (Fig. 14). The functions given to all of these controls and the content shown on the display can be freely assigned and set up from applications on a PC as requested by the individual driver. By sending information to the ECU through the garage system, the steering and ECU functions can be linked together. Frequently used and important functions are assigned to push switches and rotary switches so that those operations are carried out with one action. Other operations are placed in command hierarchies and accessed using a Mode Function switch and the "+/-" switch. This realized a balance between operability and multifunctional switchability.

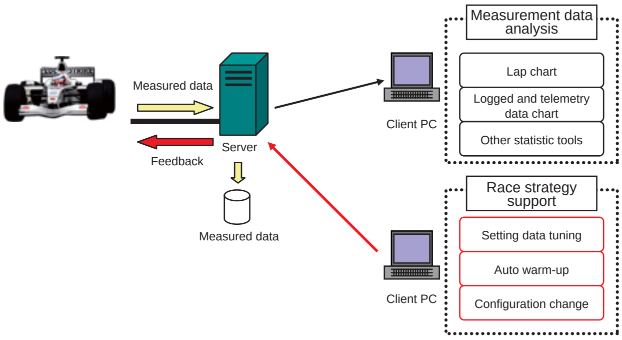

Fig. 12 Garage system

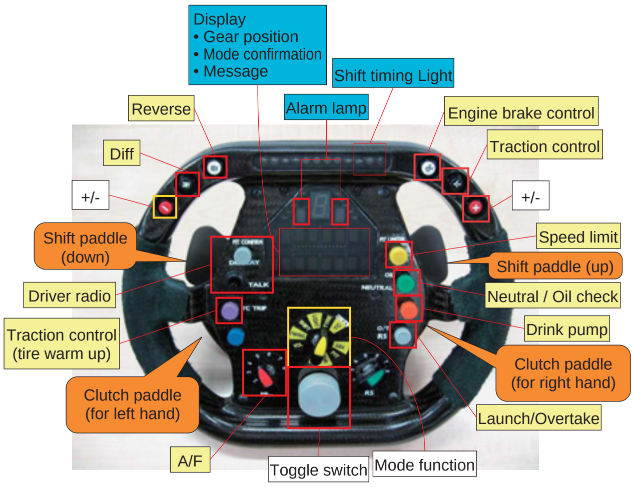

Fig. 13 Steering wheel functions

Fig. 14 Steering wheel display

5. Hardware Development

The electronic control units were given a three-dimensional structure using multiple circuit boards in order to increase the package density. Circuit boards densely populated with electronic parts have large numbers of wiring connections, and it was necessary to consider techniques for making connections between boards. Higher-performance CPUs also operate at higher speeds and generate considerable heat. Techniques for heat dissipation in miniaturized packages were an issue.

5.1. High-Density Packages

Electronic component packaging techniques that had no track record of use in automotive electronic components at that time were employed in 2003 to realize high-density packages. These were the Fine-pitch Ball Grid Array (FBGA) and the Build-up printed circuit board (PCB), and their use realized miniaturization. Figure 15 shows a circuit board populated with CPUs using the Build-up PCB technology. For the 2009 model TDL, a prototype unit was fabricated through the application of Device Embedded PCB technology. This was confirmed to achieve 20% greater packaging density than Build-up PCB products.

CPU operation at higher speeds was accompanied by faster bus clock rates and CPU electrical power supply at a lower voltage (1.8 V). This made the units more susceptible to being affected by disturbance noise and cross talk. Consequently, there was an even greater demand than before for stabilization of pattern shields and ground electric potential during pattern design, and circuit board wiring design techniques based on high-speed transmission path simulation were adopted.

5.2. Inter-Board Connection Methods

In the case of unit structure from multiple circuit boards, the method used to connect boards with signal wires becomes an issue.

Larger units involve a great number of inter-board signal wire connections. Therefore, not only the connectors can cause dead space, but it is apparent that even more space is required when wire routing is taken into consideration.

In order to resolve this issue, it was decided that the 2008 model TDL would reduce the inter-board connectors used up to that time by instead using Rigid-Flexible circuit boards to optimize inter-board wiring. At the same time, pattern shields could be built in at signal wire connections for communications and small signals, and the connections could be made electrically stable as well (Fig. 16).

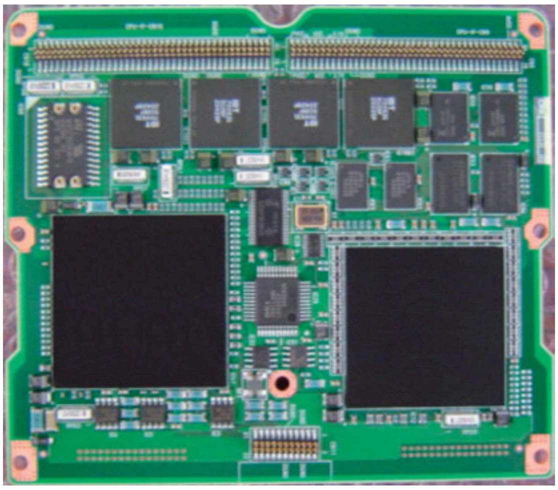

Fig. 15 High density PCB surface

5.3. Heat Dissipation Structure

Generally speaking, the automotive CPUs used in an ECU often do not require heat dissipation measures. The high-speed CPUs used in Formula One ECUs, however, have power consumption that rises as high as about 4 W, and they exceed the guaranteed operating temperature of 105°C even at room temperature (25°C).

In order to achieve a balance of high processing performance and miniaturization in the Formula One ECU, the greatest issue was how to deal with heat. This was a question of whether the unit could be made suitable for use in the actual car environment.

Heat dissipation for high-speed CPUs and other such heat generating devices is generally accomplished by forced air-cooling using heat sinks. In Formula One ECUs, for which miniaturization is sought, maximum use was made of the case and the circuit boards to enable guaranteed operation even in the actual car environment where the ambient temperature rises above 60°C.

The heat dissipation measures will be described here, using the ECU as an example. Figure 17 shows the main electronic parts that generate heat, the heat dissipation structure, and the heat dissipation pathways. It is important to dissipate the heat that is generated and to increase the heat capacity.

Regarding the former, a pattern was formed with a circuit board affixed to an aluminum plate made from the same material as the ECU case in order to enhance heat conduction from the device and the circuit board, thus using the case structure for heat dissipation. Regarding the latter, metal core PCBs were adopted for the circuit boards that have CPUs mounted. These have high heat conductivity in the planar direction, and the heat capacity of the circuit boards was increased as a result.

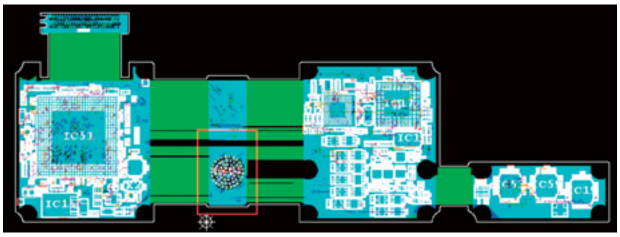

Fig. 16 Rigid-Flexible PCB of TDL

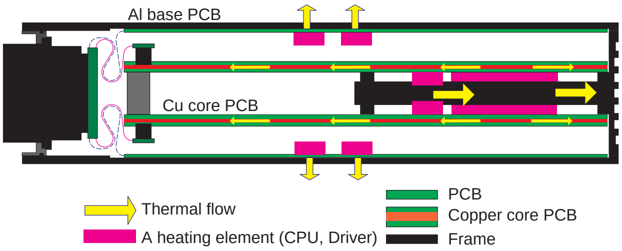

Fig. 17 High heat conditioning structure of ECU

By means of these various techniques, the unit could be made suitable for the actual mounted environment in the car.

5.4. History of Miniaturization

Figure 18 shows the historical changes in the ECU’s package size and the technologies employed. There has been demand for higher processing performance since the 2004 specifications. This was achieved employing the technologies described above, so that higher performance was realized while maintaining the size of the 2004 model.

Growing demand for higher performance and greater miniaturization of ECUs in mass production vehicles, as well, will no doubt lead to importance being placed not only on measures for heat dissipation in electronic components, but also on technology to inhibit the generation of heat in devices.

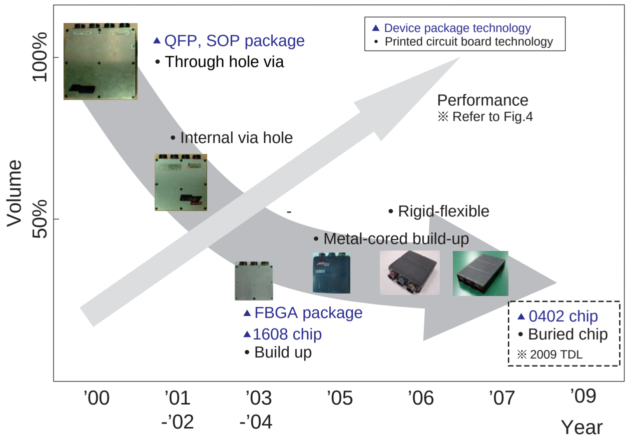

Fig. 18 ECU package

6. Telemetry

6.1. History of Telemetry Development

Telemetry is the system that takes data from the various kinds of sensor data and the like while the vehicle is running and uses radio to transmit it to the pit. Telemetry was first developed for use in races by Honda in the mid-1980s, during the second era of participation in Formula One competition. Telemetry was used during the second era by acquiring important data on engine speed, engine oil and water pressure, engine oil and water temperature, fuel consumption, and the like while the car was passing in front of the pit, and using that data to manage conditions in the car. In the third era, by contrast, that system evolved to acquire and analyze all data concerning the engine and the chassis in real time. Figure 19 shows the history of change in communication speed and communication protocols used in telemetry.

In 2000 and 2001, the telemetry system developed during the second era was carried over. Its carrier wave frequency was in the 400 MHz band, the modulation method was Frequency Shift Keying (FSK), and the communication speed was 19.2 kbps.

A change in the regulations in 2002 enabled the transmission of data from the pit to the car, initiating the development of interactive telemetry systems. The communication speed in one direction was itself increased to 38.4 kbps. In 2003, however, the regulations changed again and interactive telemetry was outlawed.

In 2004, the carrier wave frequency was moved to the 1.7 GHz band, and the communication speed was raised as high as 460 kbps.

The communication speed was further raised significantly again in 2006. Of all the data collected while running, the items required for real time analysis amount to approximately 1000 channels. To transmit these by telemetry would require a transmission speed of approximately 1 Mbps. The demand for high-precision measurement described in section 4.3. required a maximum data rate of 1 kHz. In order to meet these demands, the chosen modulation method was Phase Shift Keying (PSK), which has high-power efficiency and frequency-use efficiency as well as low error bit rates at low receiving levels. In addition, the communication speed was increased to 2 Mbps, and a trigger function that increased the rate of acquisition for certain data at specified times was also implemented.

In 2006, as a result of the evolution in technology noted above, practically all the data from running cars could be acquired by the pit in real time. This capability became an indispensable part of race operations, as the data from the start of the formation lap could be used, for example, to change the clutch control mode as the race was starting.

6.2. Issues Associated with Increased Speed

Telemetry systems were checked for data acquisition performance in a simulated desktop environment. After that, circuit tests would be implemented; however, there were many points where testing on the actual circuit and desktop simulation indicated different characteristics. This was particularly the case when Quadrature Phase Shift Keying (QPSK) was adopted as the modulation method to increase the speed. In desktop simulation, the packet acquisition rate (the percentage of data packets

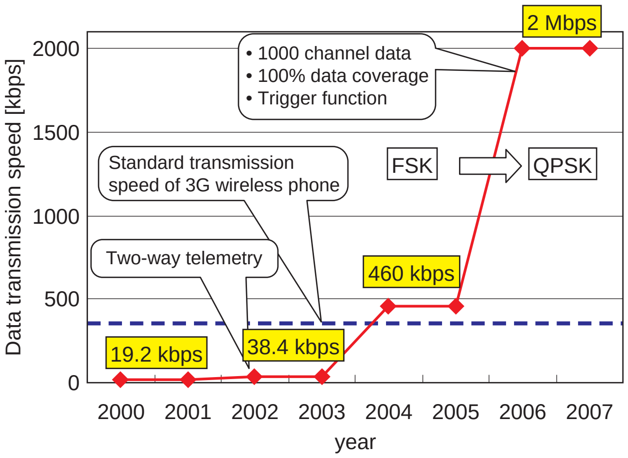

Fig. 19 Progression in telemetry transmission speed

received normally) was 90% or higher, but in circuit tests, the rate declined significantly. The data was being retransmitted, however, so the coverage (the percentage of necessary data acquired) maintained a level of about 100% (Fig. 20).

Figure 20 shows a conspicuous decline in the packet acquisition rate on the circuit, even in sectors that are relatively close to the pit. When data acquisition performance declines even at short distances, in other words, when reception levels are adequate, the cause is conceivably the influence of fading, defined as mutual interference on the receiving side from multi-pass waves, which are reflections from the circuit road surface, the stands, and the like. The extent of influence from fading depends on communication speed. Figure 21 shows how the length of a single frame is reduced when the communication speed increases, so that the amount of interference is greater proportionate to the frame length. As a result, the influence of fading becomes significant and communication quality declines.

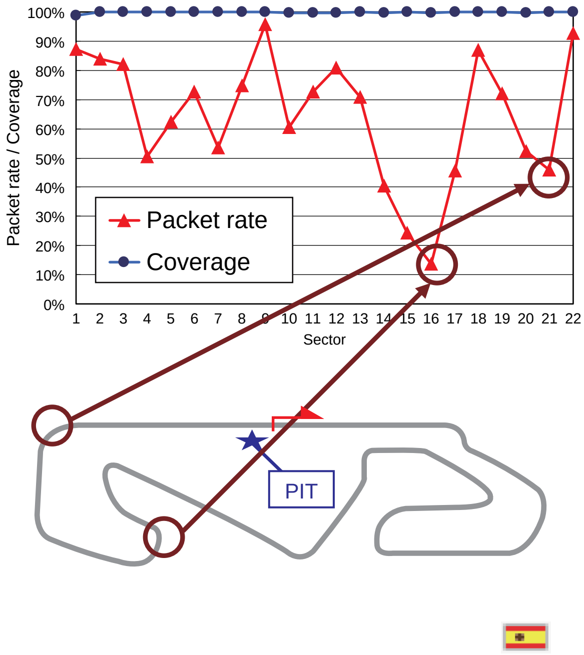

Fig. 20 Packet rate and coverage for circuit one round (2007 Catalonia)

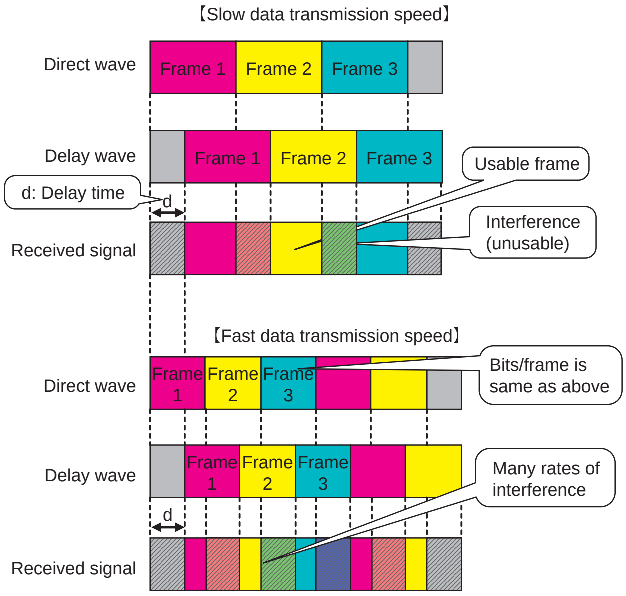

Fig. 21 Difference in influence of fading by data transmission speed

A variety of measures were tried to reduce the above type of decline in the packet acquisition rate, including:

(1) transmission power was increased to mitigate the effects of noise;

(2) transmission speed was lowered to mitigate the effects of multi-pass waves;

(3) a directional antenna was used on the receiving side in order to avoid multi-pass waves; and

(4) forward error correction (FEC) was adopted to lower the error bit rate.

Ultimately, however, these measures did not achieve any major reversal in the decline.

6.3. Consideration of a Radio Wave Propagation Model for the Circuit

As the development of telemetry depends on desktop simulation, an accurate grasp of the radio wave propagation environment on the circuit is of major importance. Consequently, telemetry development from 2007 on included efforts to raise packet acquisition rates on actual circuits by conducting investigations into radio wave propagation environments that resembled the actual environment.

The environment used for Formula One racing differs substantially from that of ordinary mobile communications (mobile phones and the like). Movement speeds can exceed 300 km/h at the maximum, there is no clear line of sight from the pit to the farthest point, and adaptive transmission cannot be used because the communication is one-way from the car to the pit.

Figure 22 shows the radio wave model (fading model) that was used in simulations up to 2007. In this model, there are two routes (paths) followed by radio waves, and the maximum delay time between paths was 0.2 μs. There is generally said to be a reflection delay time of 0.01 μs on land where the line of sight is clear, and a reflection delay time of 0.1 μs (a maximum of 0.2 μs) where there are buildings. This model is thought to diverge from the actual situation on the following two points:

(1) The path delay time is short.

The delay time of 0.2 μs represents no more than 60 m when converted into an optical path length. Considering that in the actual environment there would be reflections from distant stands, surrounding

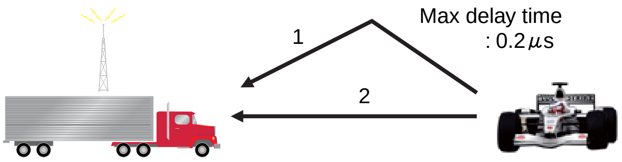

Fig. 22 Fading model used for development to 2007

mountains, and the like, it can be inferred that the path delay time would be longer.

(2) There are too few paths.

Since the telemetry transmission antenna is non-directional and transmits radio waves in every direction from the car, it can be expected that waves reflected from every structure on the course will be arriving at the receiving antenna at the pit, and the number of paths can therefore be conjectured to be greater than two.

Measurements made on site are thought to be the optimal way of ascertaining the radio wave propagation environment. As explained earlier, however, measurement on the circuit presents issues. Therefore, a variety of values were assigned as fading model parameters and the actual measured packet acquisition rate and the error pattern in data received with errors on circuit tests were compared with simulated tests. The following results were obtained:

- the maximum number of paths is six; and
- the delay times of multi-pass waves of dominant strength were about zero to 1 μs, and weaker multi-pass waves had a maximum delay of 5 μs.

It was found that the above fading model is similar to the actual environment (Fig. 23).

The above fading model is known as the Rayleigh fading model. Since the influence of overlapping multi-pass waves in large numbers can cause consecutive errors to appear in the data, little effect is generally felt from increases in transmission power or forward error correction. Furthermore, the existence of a large number of paths means that even the use of directional antennas will not fully avert the effects of multi-pass waves, and since the delay times are so long, decreasing the transmission speed of 2 Mbps to just one-half or one-quarter cannot be expected to resolve the issue of communication quality. When the model in Fig. 23 is viewed in this light, it becomes quite understandable that the measures described in section 6.2. to address the reduced packet acquisition rate did not yield any major effects to better the situation.

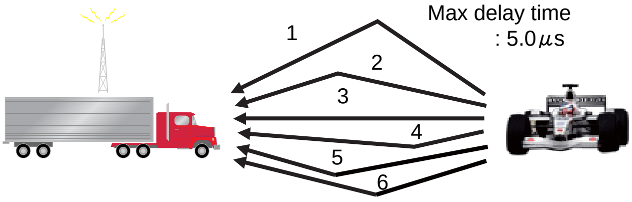

Fig. 23 Fading model used for development from 2008

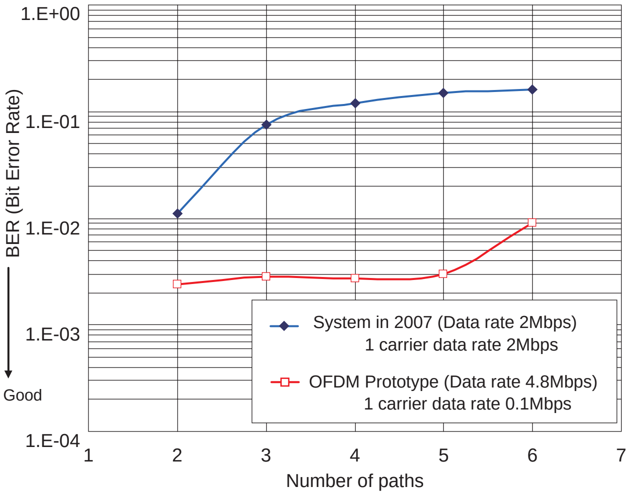

Fig. 24 Comparison of conventional system and OFDM

In development from 2008 on, the model in Fig. 23 was employed to conduct evaluations of new communication protocols to realize higher-speed communications while still maintaining an adequate packet acquisition rate even under this model.

6.4. Technology for Next-Generation Telemetry

The aim from 2009 had been to do away with downloading by developing a system that uses real time telemetry to transmit all the data that has been logged by the ECU and the logger up to that time. Investigation was in progress with the goal of achieving further increases in speed. In order to seek still greater speed under present circumstances, it is important to adopt a multi-carrier system capable of reducing the transmission rate separately by carrier as a measure to increase fading resistance. Conceivable specific techniques to realize the aim of increased speed include the use of Orthogonal Frequency Division Multiplexing (OFDM) for enhancement of frequency-use efficiency and fading resistance.

A prototype for desktop use of OFDM was created and an evaluation of its characteristics was carried out using the fading model shown in Fig. 23. Figure 24 shows a comparison of the characteristics of the telemetry transmission equipment from 2007 and the OFDM prototype. The vertical axis in Fig. 24 represents the Bit Error Rate (BER: the number of bit errors divided by the number of bits transmitted) while the horizontal axis represents the number of fading paths. It can be confirmed that the adoption of OFDM has realized higher speed and higher reliability.

7. Component Development

As the Formula One engine and chassis have 100 or more sensors and actuators mounted on them, miniaturization of these devices was required with a view to mountability. Particularly, sensors mounted on the engine (for measuring pressure, temperature, timing, and throttle position), along with ignition coils and the alternator, were thoroughly miniaturized and made highly efficient. In addition, the greatest issue was the guarantee of their sustained functionality under engine vibration.

This article will provide details on the development of the following:

(1) throttle position sensor; and

(2) engine wire harness

7.1. Throttle Position Sensor

In the engine of an ordinary automobile, the intake flow is measured by the intake manifold pressure or by using an air flow meter, and that measurement is used to control the fuel injection volume. In the highly responsive engines used for racing and the like, however, the throttle opening is taken as the basis for setting the fuel injection volume. The throttle position sensor, therefore, is one of the key sensors in a Formula One engine, and requires high accuracy (within 1% at Full Scale) and reliability.

When Honda returned to Formula One racing in 2000, the brush type of contact sensor (potentiometer) was initially being used. There were various issues with it, however, including wear of the brush contact surface from vibration and foreign matter (such as oil or dust). As vibration from the engine reaches approximately 500 G, there was an urgent necessity to isolate the sensor from contact for the purposes of accuracy and reliability. From late 2003, therefore, this sensor was changed to a non-contact type using a magneto-resistance (MR) element to detect the magnetic vector. As this is the basic sensor for fuel injection control, it is necessary to provide high accuracy across the entire temperature range. An IC using two MR elements was adopted, and accuracy was assured by a technique that cancels out their respective temperature characteristics.

A split type sensor was adopted that has the sensing element mounted on the throttle body, and a magnet (polarized to generate the desired magnetic field) attached to the shaft of the throttle butterfly, which is a rotating body (Fig. 25).

This sensor was mounted toward the back end of the engine, and heat damage occurred frequently.

The main cause of heat damage was exhaust heat from the exhaust manifold. Due to the aerodynamic requirements of the chassis, the engine cowl was being squeezed to a smaller size every year. This had an impact on the flow of air inside the engine cowl, in addition to which the layout of the exhaust manifold was also changed accordingly so that it was closer to the engine where the sensor was mounted. The result was an increasingly harsh thermal environment. Even when the MR element and other IC parts are guaranteed at high temperatures, such guarantees ordinarily cover up to 130 °C. In order to guarantee up to 150 °C for racing, high-temperature solder and other such materials were used, while the range of guaranteed accuracy was restricted and adjustment made by means of software. Through these and other such measures, sensor accuracy was able to satisfy the condition of staying within 1% FS.

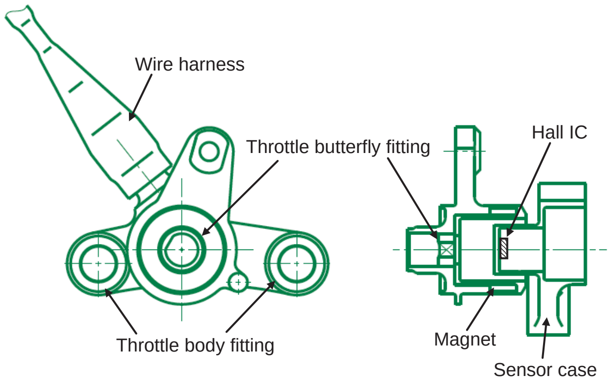

Fig. 25 Throttle sensor

7.2. Wire Harness

The Formula One wire harness was designed with an emphasis on reduced weight, durability, and on-site maintainability. Up until engine homologation was prescribed in 2007, there were no engine weight regulations. Consequently, measures were specialized in weight reduction, and the wire harness was fixed in place using simple stays that were mainly placed around the airbox and cylinder head. When engine weight regulations were instituted, there was a shift in orientation to maintainability and reliability rather than weight reduction. A junction box was placed above the cylinder head and the circuits for all the sensors were brought together in that box (Fig. 26).

In terms of reliability, it was a struggle against breaks in the wires. The top speed of a Formula One engine is double or more that of a mass production vehicle, and normal engine speed extends across the entire range, so that areas around the engine are subject to constant high-frequency vibration. In the case of a mass production vehicle, the wire harness is bunched together with tape or other such material and then encased in outer sheathing material (plastic tube) to counter wire breakage and wear at points of contact due to vibration. In Formula One cars, since the use of finer wires and reduction in weight are also important objectives, heat-shrink tubing made of woven polyester fiber is used to protect against external contact as well as to realize the use of finer wiring and lighter weight. Wire breakage resulting from tension load on the harness generated by vibration and acceleration has further been addressed by the use of silver-plated high-strength copper wire for racing use. The harness wires are then twisted together and bundled inside shrink tubes, enhancing harness

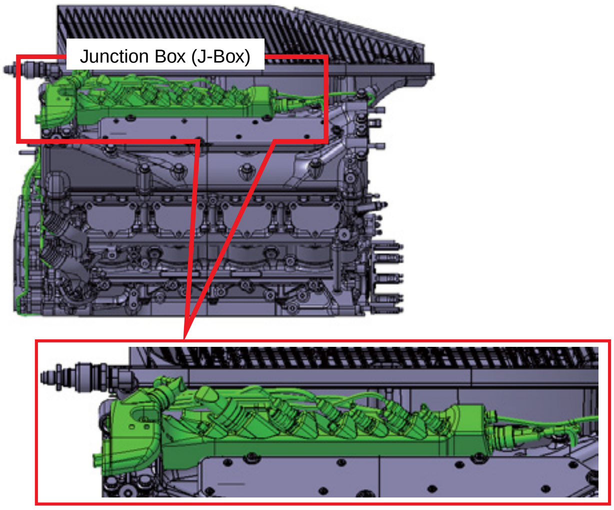

Fig. 26 Junction box on engine

strength against breaks (Fig. 27). This twisted structure not only enhances strength against wire breakage, it also heightens the flexibility of the harness itself and enhances engine mountability.

Even when these techniques are used, however, there are still places on the engine where vibrations at the level of several hundred Gs are generated. There have been cases, therefore, where just the copper wire has broken inside its cladding or inside the shrink tubing even when no external damage is visible. This is thought to be generated by sympathetic vibration of the copper wire or of the harness itself due to the high-frequency vibration, and the vibration is conjectured to result in displacement and tensile loads that cannot be absorbed. The method was therefore adopted of fixing the entire harness in place between the attachment points, including the oscillating parts, by encasing it in rigid retaining parts made of carbon material. This has succeeded in preventing wire breakage.

Vibration has been an unavoidable obstacle in the course of Formula One development. In the initial phases of development, it was important to grasp the levels and patterns of vibration in advance and to skillfully combine the measures taken to counter them. Another point is that the short Formula One development period allows limited opportunities to conduct the durability checks under engine operating conditions that are necessary to guarantee reliability. Consequently, it is necessary to ascertain the symptoms of faults and the effectiveness of countermeasures early on, and methods of analysis using X-ray and other such non-destructive inspection devices in durability testing have been introduced to the harness development process.

It has been necessary to manage the design effort so as not to interfere with weight reduction measures by pursuing vibration-resistant design that goes beyond what is required in actual vehicles.

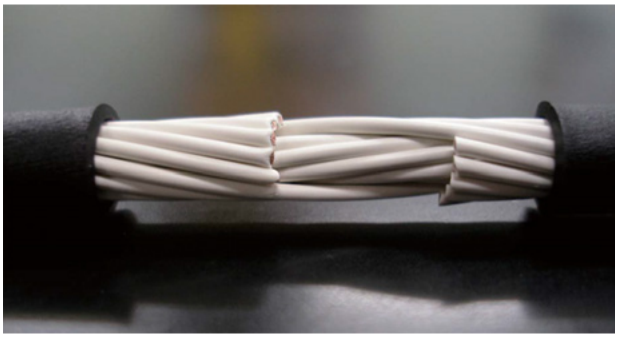

Fig. 27 Harness

8. Conclusion

In retrospect, Honda’s Formula One system development proceeded without break from the time of the test runs at Pembrey Circuit in the United Kingdom in 1999, one year after their development started, up to the Brazil Grand Prix in 2007, and a wealth of findings regarding new technology has been obtained. The electronic control systems developed for Formula One are for unique vehicles and are further specialized for racing functionality. However, the conceptual approach to system construction and the basic electrical system technologies that were employed are also likely to be held in common with the advancing automotive technology of the future.

It has been decided that the development of electrical and electronic technology for Formula One racing underway since the adoption of FIA standard systems will be superceded by the development of kinetic energy recovery systems (KERS), which is employed from 2009. It is to be hoped that Formula One will continue to stand as the highest achievement in automobile racing, as well as the highest achievement in automotive technology in times to come.

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