

Semiconductor Products for ITS Applications

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OVERVIEW: Automobiles in the ITS (intelligent transport systems) age incorporate information terminals with communication, data processing and mobile multimedia functions. These terminals will make it possible to access information services that are included in the ITS communication infrastructure and are expected to work in conjunction with existing car electronics control and information systems resulting in more complete car navigation, data processing, and driving safety functions, etc. To fulfill the needs of the ITS era, Hitachi, Ltd. continues to develop various semiconductor products that are essential to electronic control, driver information, communication and safety, including high-performance microprocessors and high-frequency devices for real-time control, multimedia processing and communications.

INTRODUCTION

AUTOMOBILE traffic systems developed so far include infrastructure and in-vehicle electronics. The evolution of the in-vehicle electronics system includes the integration of electronic controls, control system network and the development of new control systems, such as advanced safety and automated driving systems. On the infrastructure side, too, cooperation between automobiles and infrastructure is being promoted by the improvement of data communication networks such as VICS (vehicle information and communication system) and DSRC (dedicated short range communication) and a variety of driver information services to make transportation more convenient. We believe that the combination of an information and control network works to implement increasingly sophisticated functions for car navigation, data processing and driving safety for automobiles in the ITS era.

Among the various semiconductor products for ITS, this paper covers high-frequency devices for millimeter-wave radar, which are key devices for advanced safety vehicles; SuperH microprocessors for real-time engine and transmission control; the graphics core and voice recognition/synthesis middleware that run on the SuperH microprocessors and that are essential for car navigation; and in-vehicle information systems.

GaAs DEVICES FOR MILLIMETER-WAVE RADARS

Overview of the Millimeter-Wave GaAs MMIC

Vehicle-mounted radar is attracting attention as a system for supporting automobile driving safety and the 76 GHz millimeter-wave frequency band has been allocated in Japan, the US and Europe as a common world-wide frequency for that purpose. Millimeter-wave radar is currently being introduced in the market by some automobile manufacturers. All of the products in question employ a radio transceiver that comprises discrete components. In the future, to accelerate the popularization of car radar, it will be necessary to achieve low cost and mass production by designing an integrated circuit chip for the millimeter-wave radar transceiver, the principal component of the radar system.

Hitachi, Ltd. has been developing a fabrication process and integrated circuits for a millimeter-wave GaAs (gallium arsenide) MMIC (microwave monolithic IC) and has also completed a compact unitized transceiver and antenna module using that MMIC and confirmed its radar performance.

Structure and Features

The cross-sectional structure of the "P-HEMT" transistor, which was developed as the active element of the MMIC for application in radar systems, is shown

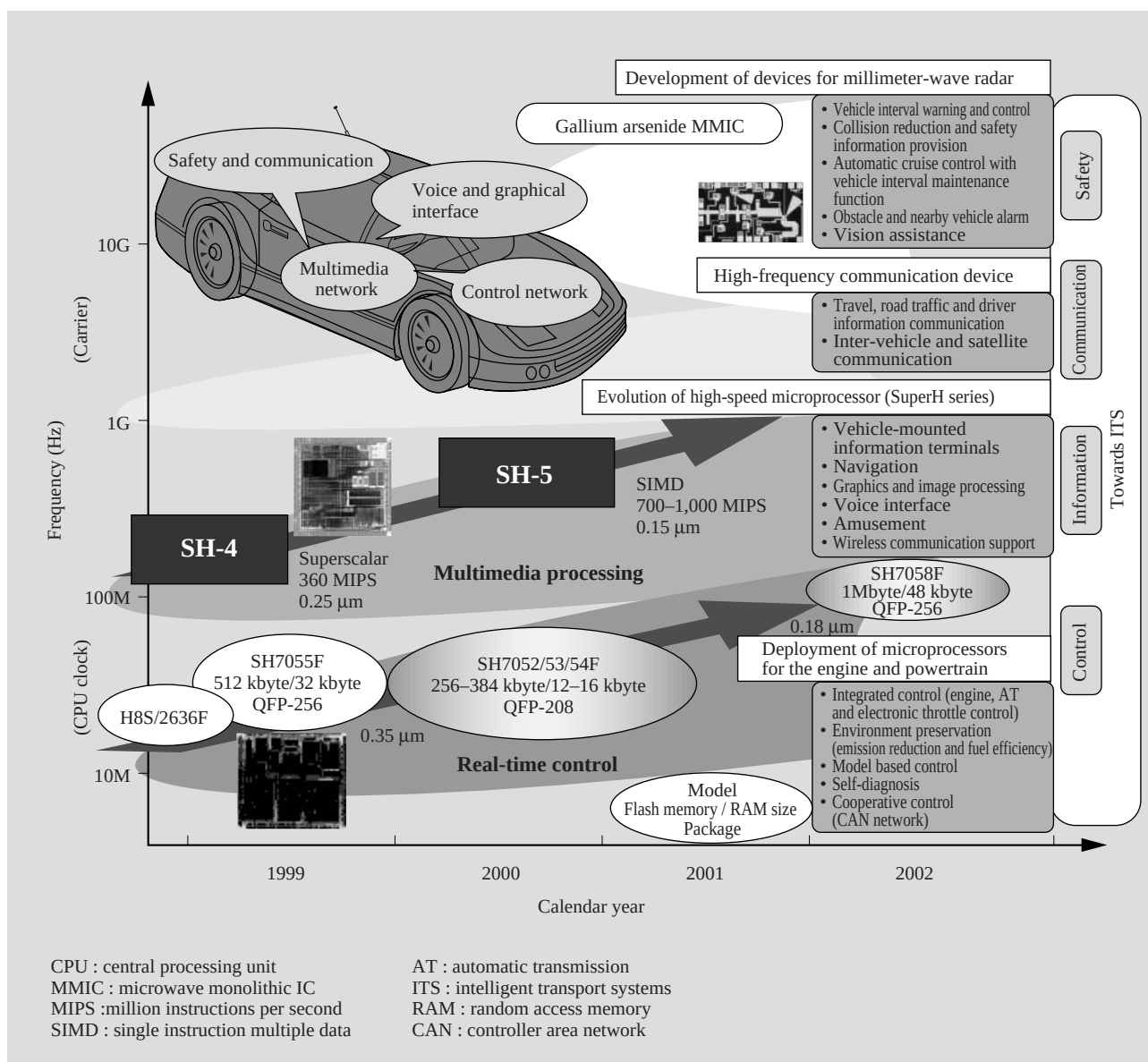


Fig. 1—Development of Semiconductor Technology and Products for the ITS.

Automobiles of the ITS age will be equipped with information terminals that have communication and multimedia functions which work together with the conventional engine and powertrain control systems and implement navigation, data processing, driving safety, and other such functions over an information and control network. Hitachi, Ltd. is developing products such as high-performance microprocessors and high-frequency devices for the advancement of vehicle-mounted devices for the ITS.

in Fig. 2.

To obtain high performance, this device employs a layered structure of GaAs materials rather than silicon. The metal gate terminals, which govern the millimeter-wave characteristics, are formed with a gate length of 0.15 μm , and millimeter-wave current flow between the drain terminal and source terminal is controlled. The MMIC is constructed, by forming thin-film

resistors and thin-film capacitors, millimeter-wave metal transmission line elements and other such circuit components on the same GaAs wafer, with this transistor serving as the core (see Fig. 3). The radar transceiver configuration and photographs of the newly developed millimeter-wave voltage controlled oscillator, power amplifier, and receiver MMIC chips are shown in Fig. 4. To reduce the chip size, which is

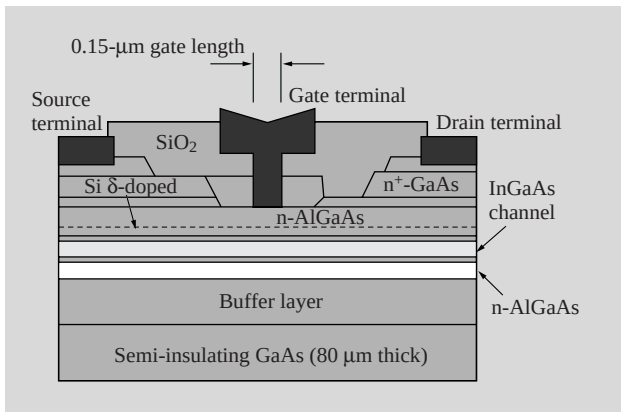


Fig. 2—Cross-sectional Structure of the P-HEMT Transistor. The P-HEMT (pseudomorphic high electron mobility transistor) employs a layered structure of GaAs materials rather than silicon in order to obtain high performance, and controls millimeter-wave current between the source and drain, by a 0.15-μm long gate terminal.

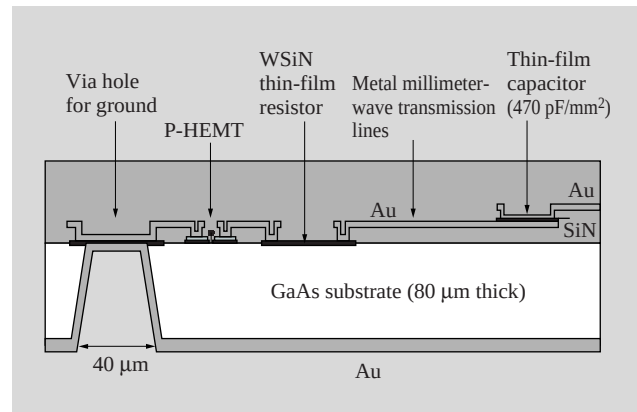


Fig. 3—Cross-sectional Structure of the MMIC. With the P-HEMT as the core, thin-film resistors and thin-film capacitors, millimeter-wave metal transmission line elements and other such circuit components are formed on the same GaAs wafer.

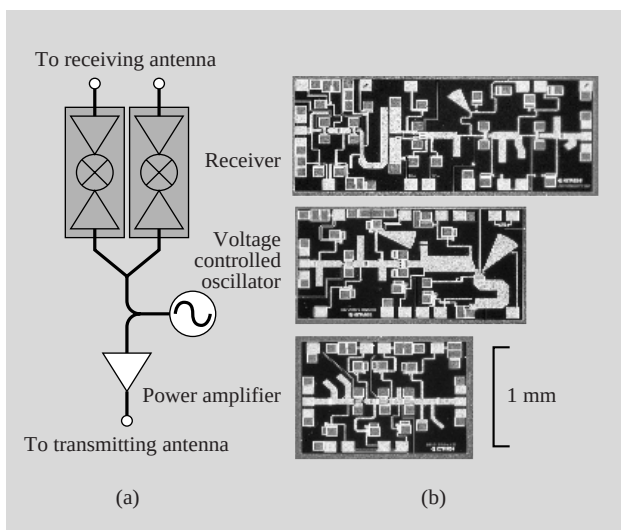


Fig. 4—Radar Transceiver Configuration and MMIC Chip Set. The radar transceiver configuration (a) and photographs of the three MMIC chips (b) are shown. To achieve a smaller chip size, fundamental-frequency oscillation is used and a three-dimensional electromagnetic analysis was done to reduce the interference among the circuit elements. The result is a total chip area of 7.9 mm².

the key to reducing cost, the oscillator MMIC generates the 76 GHz signal directly. Also, in the circuit design, a three-dimensional analysis of interference among the circuit elements was employed to reduce the chip size. The result was a total chip area of 7.9 mm².

Millimeter-wave Radar System

In the radar transceiver, the millimeter-wave signal from the oscillator MMIC is amplified by the power

amplifier MMIC for transmission and then transmitted by the transmitting antenna. The millimeter-wave signals that are reflected from multiple vehicles in front of the vehicle on which the radar is mounted are received by two receiving antennas. Those signals are compared with the reference signal by the receiver MMIC, and the signal, which contains information on the speed, distance and direction of the vehicles in front, is output to the signal-processing unit of the radar system. Planar antennas, which have the merit of thin profile, are used for transmitting and receiving antennas. By integrating these antennas and the MMIC transceiver described above into a single unit, all of the millimeter-wave functions required for radar operation are implemented in a 63 × 93 × 5 mm module, making it possible to realize an overall radar system that is compact and light in weight. (For more information on the radar system, see the separate article in this special issue).

SuperH MICROPROCESSORS FOR REAL-TIME CONTROL SYSTEMS

Product Evolution

As one of the MCU (micro-controller unit) products for real-time control, the SH7050 series is being used for automotive applications such as engine, powertrain and vehicle control. The SH7055F can be used with CAN (Controller Area Network) and OSEK-OS, the standard real-time OS (operating system) in the automotive industry. It also has an FPU (floating point processing unit) to allow the implementation of highly

sophisticated control methods. Furthermore, it is equipped with AUD (advanced user debugger), which is a standard hardware debugger interface in the automotive applications, contributing to a reduction of the development period.

Application to Engine and Vehicle Control

To satisfy strengthened regulations concerning automotive emission reduction, fuel efficiency and self-diagnosis, as well as to achieve rapid deployment of the ITS, embedded software for engine and vehicle control is becoming complex and large in scale.

That has created a need for even more computing power and memory capacity. The SH7050 series of 32-bit RISC microprocessors has abundant processing power and flash memory on-chip and can also be used with new development methods. The importance of efficiency in software development is also increasing, and so car and parts manufacturers are beginning to employ new software development methods.

In the development of the software embedded on ECU (electronic control unit) for real-time control

systems, the procedure shown in Fig. 5 is becoming standard. The use of RPT (rapid prototyping) in control algorithm design makes it possible to check control performance on the vehicle itself rather than by simulation alone. This check can be performed through slight modifications of the ECU software. With this method, the ECU and an RPT unit for computing work together as described below.

(1) The sensor data is transferred from the ECU to the RPT unit for computing via CAN or AUD.

(2) In the RPT unit, the newly developed control algorithm is executed on the basis of the sensor data and the obtained results (actuation data) are returned to the ECU.

(3) In the ECU, this actuation data is used in place of original data (the original processing is bypassed) to control the ignition, fuel injection, etc.

Here, in order to prevent degradation of control performance by this bypassing, it is necessary to return the actuation data to the ECU prior to the time at which the ignition, injection, etc. are to be executed. By taking advantage of the high-speed data transfer function of

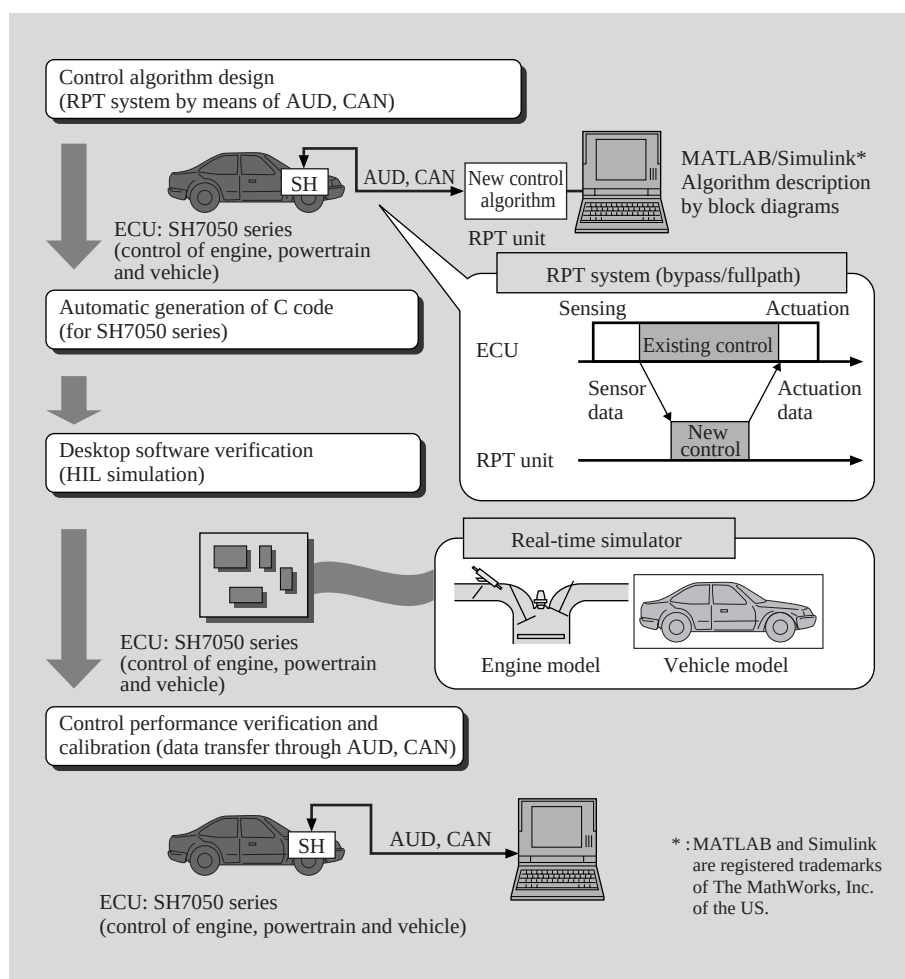


Fig. 5— Development Procedure for Automotive Control Software.

This procedure, rapid prototyping (RPT) and hardware in the loop (HIL), for the efficient development of real-time control system software for embedding in single-chip microprocessors, is now spreading rapidly in the world.

the AUD on the SH7055F, however, it is possible to construct a highly efficient RPT environment that provides accurate execution timing.

Application Results

In the RPT process mentioned above, algorithms newly developed can be described in a fashion of block diagrams using a popular control system CAD tool, such as MATLAB/Simulink. Once the evaluation of a newly developed algorithm is finished, the block diagrams are converted to C codes automatically on the CAD tool. Here, C code conversion based on the CAD tool is much more accurate and reliable than that of manual coding by programmers. Another major benefit is that it is nearly unnecessary to change the software of the ECU when testing the new algorithm on an actual vehicle. Recently, conversion tools have been generating machine-dependent C codes for a particular microprocessor such as the SH7050 series. The next step for software verification is HIL.

According to the HIL concept, before calibration of an ECU attached on an actual vehicle, embedded software is verified with a real-time engine simulator to increase efficiency and safety in testing with reduction of labor. The introduction of HIL is currently spreading to car and parts manufacturers.

Control system optimization during the verification and calibration process becomes efficient by high-speed access to the internal memory of the microprocessor using the debugger interface (serial communication, AUD, etc.) of the SH7055F.

GRAPHICS TECHNOLOGY FOR CAR NAVIGATION

Q Series Graphics Processors

Car navigation screens and other such display devices are a pivotal part of the user interface of automobile information systems. Because the space inside automobiles is small, the system should be as small as possible and information display resolution should be high enough to allow accurate display of information, even on a small screen. Therefore, Hitachi, Ltd. has developed the Q Series graphics processors for use together with our SuperH series high-performance microprocessors.

Memory Integration Technology for Achieving Smaller Systems

In the Q series, making use of high-speed memory, video data, drawing commands, drawing data, and display data, which are conventionally managed in

separate memory storage, are stored in an unified image memory device. That made it possible to configure a minimal graphics subsystem with only the Q series and memory (see Fig. 6). The HD64413A (Q2SD) is equipped with functions for inputting and displaying digitized video data, simplifying PinP (picture in picture) and other such peripheral logic elements. In addition, using memory devices that operate at 66 MHz makes it possible to draw 90,000 25×20 pixel rectangles per second.

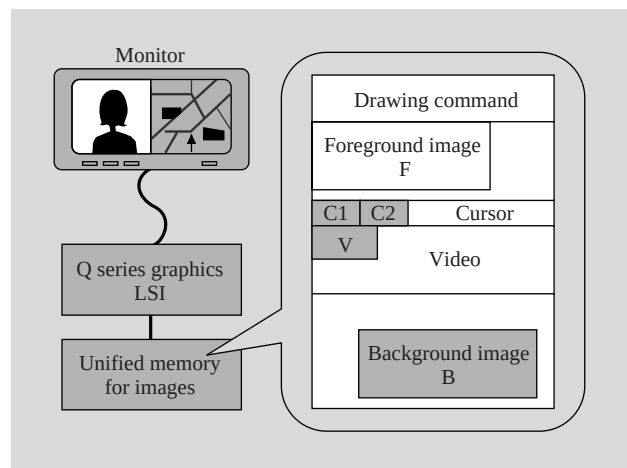


Fig. 6—System Configuration with the Q Series Processor. The system is simplified by storing the data in a unified memory unit.

Display and Drawing Functions Suited for Map Display

The Q series improve car navigation performance with functions for composite display and map drawing (see Fig. 7). The display function has a display scrolling function that is implemented in hardware to simplify the map drawing control software for speedy execution of the target map setting, etc. (plane B in Fig. 7). On the other hand, the display of cursors, which are used to point and mark, menus and buttons that do no scroll, and video windows etc. is handled by defining respective memory areas for those features (Planes C1, C2, F, and V in Fig. 7), which can then be composed on the display.

The main shapes used in maps include polygons for representing rivers and sea, wooded area, urban areas, and so on, roads and railways, contour lines, broken lines for representing boundaries, and text characters for place names. Focusing on this point, we employed a command system that has the functions needed for maps, with polygon drawing, patterned broken line drawing and the color display of binary

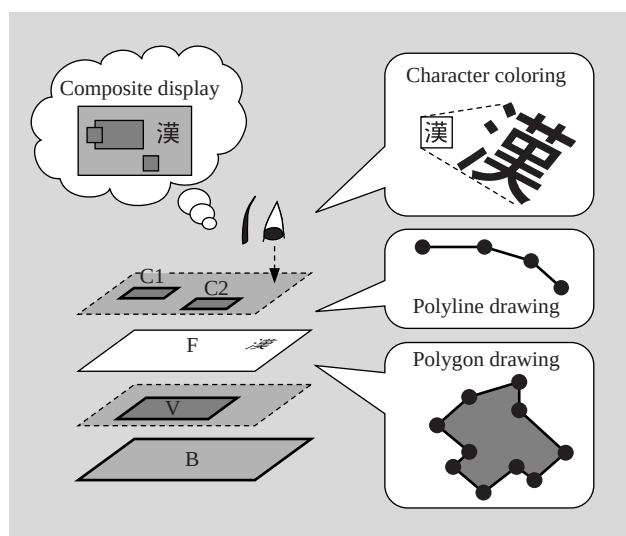


Fig. 7—Map Display Graphics Function.
Employing the composite display for high-speed scrolling and map drawing function.

text data as the drawing functions. Doing so makes it possible to achieve a system performance that cannot be attained with drawing chips that have only functions for drawing triangles and filling them with paint patterns.

SPEECH MIDDLEWARE SUPPORTING CAR MULTIMEDIA SYSTEMS

The demand for in-car terminals for the ITS due to the progress in car navigation systems has increased. This trend leads car multimedia systems or CIS (car information systems), which need three necessary elements: comfort, information services and safety. A key technology to realize these essential elements is middleware (see Fig. 8).

The voice processing middleware consisting of voice recognition and voice synthesis is described below.

Middleware for Microprocessor

Software that intermediates between user applications and the main microprocessors and that is optimized for the internal functions of the microprocessors is called middleware. The special features of middleware as total solutions are illustrated in Fig. 9. Conventionally, voice processing and image processing are performed using microprocessors and dedicated LSI chips. However, with the increasing performance of microprocessors, it has become possible to implement those functions in middleware alone. Special features of middleware are lower cost,

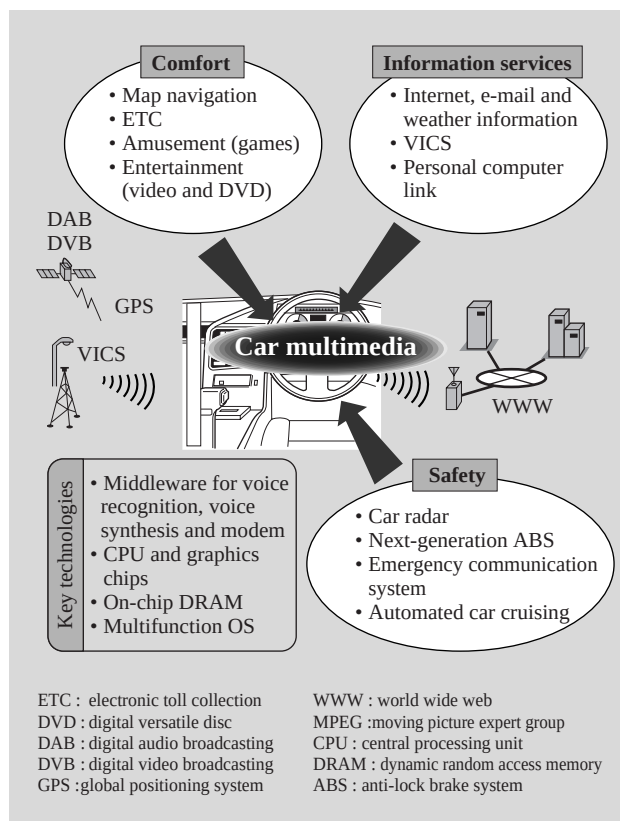


Fig. 8—Future Car Multimedia Systems.
The three essential elements of car multimedia are comfort, information services and safety. The key technology for implementing these elements includes middleware for general-purpose microprocessors, high-speed and high-quality graphics, microprocessors with on-chip memory, and multi-function real-time operating systems.

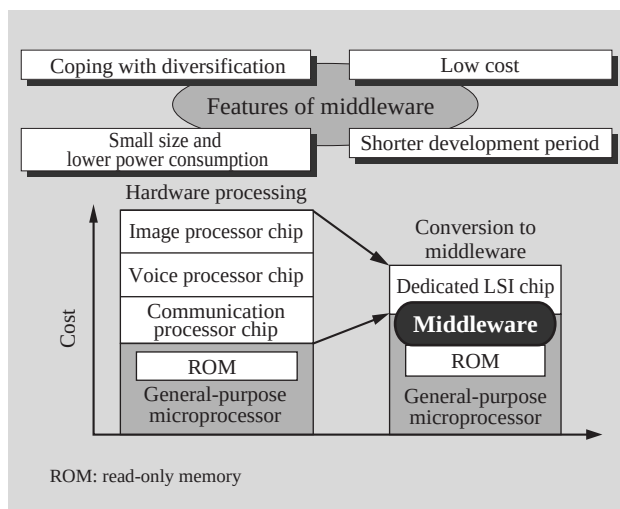


Fig. 9—Middleware as the Solution.
Conventionally, voice processing and image processing have been performed by dedicated chips. Now, as microprocessor processing power is increasing, it has become possible to implement those functions in middleware alone. Employing middleware makes it possible to achieve lower cost, smaller size and lower power consumption, as well as diversification by simply changing the program. Thus, lower cost and a shorter development period can be attained.

a smaller unit, and lower power consumption achieved by eliminating specialized speech/image chips. This also means that diversification in voice and image processing can be accommodated by simply replacing the program, thus making it possible to lower cost and shorten the development period.

To provide total solutions to SuperH microprocessor users, Hitachi, Ltd. is developing middleware products for voice, image, and communication processing.

Basic Specifications of the Voice Recognition Middleware^{5, 6)}

The specifications of the voice recognition middleware developed using SuperH microprocessors as CPUs are listed in Table 1. The recognition method is the phonemic-based HMM (Hidden Markov Model). The vocabulary size is 2,000 words, which allows implementation of a realistic car navigation service with a processing power of about 60 MIPS (million instructions per second).

On the other hand, to prevent degradation of the recognition rate in a practical environment, a special noise handling method and a speaker adaptation method are needed. As the noise handling method, in addition to the use of an environment adaptation model, in which a noise model calculated from the noise of the environment is superimposed on the acoustic models, we have developed a spectrum subtraction (SS) method, in which estimated noise in the spectrum is removed. We have also developed a speaker adaptation scheme with learning, in which standard acoustic models are modified by the utterance of several words prior to actual use. These methods are implemented as voice recognition middleware.

Evaluation Results for the Voice Middleware

We evaluated the proposed noise handling method in a driving environment. For vehicle noise, we chose driving speeds of 50 km/h and 100 km/h, and some special cases when the vehicle was going through a tunnel. The evaluation task was the recognition of 1,000 railway station names. The conventional acoustic models and the proposed acoustic models learned by including various noises, were compared. We confirmed that the proposed noise handling method is effective.

TABLE 1. Main Specifications of the SH Voice Recognition Middleware

The phonemic-based HMM is used as the voice recognition method and a noise handling method, and speaker adaptation method are employed for robustness against changes in the environment and in the speakers.

Item		Description	
Processing cycle		60 MHz	
External bus		60 MHz/32 bit	
Sampling frequency		11 kHz/12 kHz/16 kHz	
Voice recognition	Acoustic model	Phonemic-based semi-continuous HMM	
	Frame interval	10 ms	Frame: sampled data sequences
	Frame length	20 ms	
	Processing time	12 ms per frame	
	Response time	Less than 0.6 s	
	Vocabulary	2,000 words, 11 digits of consecutive numerals	
	Memory	200 kbyte (acoustic model, dictionary) 500 kbyte (work area)	

CONCLUSIONS

The keys to rapid evolution of the ITS are to provide ordinary users and drivers with desired information in a timely fashion and safe and comfortable functions and information services that are pleasant and truly convenient.

We have described microprocessors for real time engine and transmission control, graphics technology and high speed middleware for car-navigation, and high-frequency devices for car electronics in the ITS era.

By pushing forward with even further development of semiconductor technologies, and by introducing real-time control, millimeter-wave radar, car navigation, voice processing, video processing, inter-vehicle communication, network data communication, amusement, and other such elemental technologies that meet the needs of the ITS era, Hitachi, Ltd. will continue to contribute to the early maturity of advanced safety vehicles and advanced transportation systems, beginning with car multimedia.

REFERENCES

- (1) H. Kondoh et al., "77 GHz Fully-MMIC Automotive Radar," IEEE, GaAs IC Symposium Digest (Oct. 1999).

- (2) K. Kamozaki et al., "A 77 GHz T/R MMIC Chip Set for Automotive Radar Systems," IEEE, GaAs IC Symposium (Oct. 1997).
- (3) S. Takatani et al., "Millimeter-wave HEMT and MMIC for Automotive Radar," Japan Society of Applied Physics, Solid State Physics and Applications Dept. (May 2000).
- (4) H. Ohta et al., "High Performance P-HEMT with an Offset Gate Structure for Millimeter-wave MMIC's," SSDM, 430 (1997).
- (5) N. Hataoka et al., "Voice Middleware for SuperH Microprocessors," *Hitachi Hyoron* **80**, 527-532 (July 1998) in Japanese.
- (6) H. Kokubo et al., "The Introduction of Voice Recognition and Synthesis Middleware for General-purpose Microprocessors," Information Processing Society of Japan, 25th SLP Conference, 99, 14, 33-34 (Feb. 1999).

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