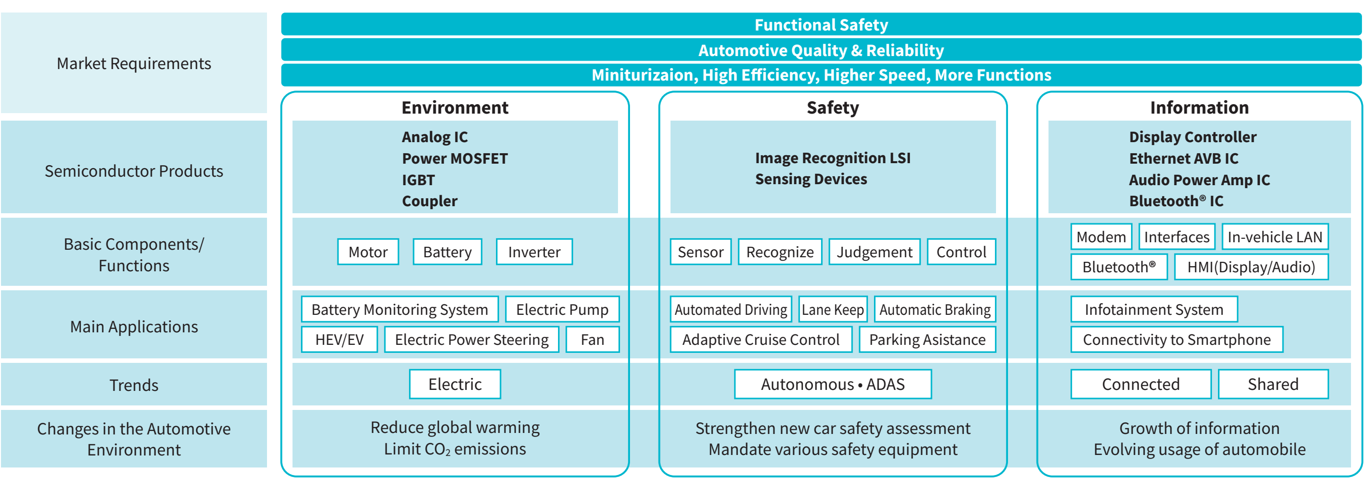
CASE Trends for Next-Generation Vehicles and Toshiba's Approach to Automotive Semiconductor Devices

In line with the recent connected, autonomous, shared, electric (CASE) trends in the global automotive industry, advanced automotive semiconductor devices are becoming increasingly important for the realization of next-generation CASE vehicles. In the field of electrification represented by electric vehicles (EVs) and hybrid EVs (HEVs), semiconductor devices with compact dimensions, light weight, and high efficiency are required to monitor and control motors, batteries, and other devices. In the field of advanced driver-assistance systems (ADAS), high-performance processors for path-planning and decision-making functions as well as highly accurate sensing and recognition functions are required accompanying the increase in demand for automated driving systems. Moreover, for exchanges of information with external equipment by means of cloud computing, communication functions, cooperative functions with mobile devices, high-speed in-vehicle local area network (LAN) functions, and enhanced security functions are required.

In response to these trends, Toshiba Electronic Devices & Storage Corporation is promoting the development of a wide variety of advanced automotive semiconductor devices and contributing to the progress of CASE technologies.

1. Introduction

Traditionally, the factors that determined the product value of a car consisted of driving, turning, and stopping (mainly the engine, transmission, chassis, etc.). However, current trends emphasize the environmental, safety and information aspects. The overview diagram of this feature article depicts the trends and requirements of the automotive market together with the semiconductor products of Toshiba Electronic Devices & Storage Corporation. In particular, looking at the role of cars in the society of the near future, elements of CASE (Connected, Autonomous, Shared, Electric) are receiving close attention.



MOSFET: Metal Oxide Semiconductor Field Effect Transistor IGBT: Insulated Gate Bipolar Transistor AVB: Audio Video
Bridge I/F: Bridge Interface HMI: Human Machine Interface CO_2: Carbon Dioxide

Overview: Growing sophistication of automotive semiconductor devices to meet automotive market needs

2. Automotive market trends

According to Strategy Analytics, from 2016 to 2024, the production of automobiles is expected to increase at an annual average growth rate (CAGR) of 2.2%. On the other hand, during this period, the growth in production of automotive semiconductors is predicted to show a CAGR of 4.5%, greatly exceeding that of the cars themselves. Especially notable is the growth in production of the semiconductors related to electrification, automated driving and ADAS[1].

Also, in addition to the above, new demand for mobile equipment connected to these cars, homes, infrastructure and services is being created.

2.1 Electric

In recent year, in view of issues such as global warming and environmental pollution, national standards and legislation on carbon dioxide (CO_2) emissions and mileage are being established by many countries.

Trends in the average permitted CO_2 emissions per car in major countries and regions are shown in **Table 1**. As can be seen, the regulations will be strengthened step by step. For example, the CO_2 emissions must be reduced to 1/2 of current levels by 2030 in Europe.

By 2030 in India and Germany and by 2040 in Britain and France, sales of new cars running on gasoline or diesel engines alone will be prohibited. Furthermore, in legislation on new-energy vehicles (NEVs), China is mandating that EV and plug-in hybrid EV (PHEV) cars together account for at least 10% of new car sales. Countries are announcing the eventual phasing out of engine-driven vehicles (gasoline and diesel cars), leading to reduction in manufacturing of such cars and the introduction of penalties associated with actual CO_2 emission levels and EV sales volume ratios. HEVs have been treated as environmentally friendly cars until now but are gradually being excluded from government subsidies and other preferential treatment, leaving the electric-powered cars (EV, PHEV and FCEV (fuel-cell electric vehicle)) as the categories with the most promising growth.

To meet the CO_2 regulations in different regions, electrification of the drive system is accelerating. According to the International Energy Agency (IEA), gasoline-powered vehicles will begin to decline after 2020, and by 2050 the sales of electric-powered cars will reach roughly 3/4 of the total (EV and PHEV 60% and FCEV 20%). (See **Figure 1**)[2].

The main issues of current electric-powered cars are insufficient driving distance, long charging time, and deterioration of battery performance. Improvements are being made for all of these issues. To extend driving distance, one must either increase battery capacity or reduce vehicle weight or reduce power consumption.

(1) Battery capacity increase

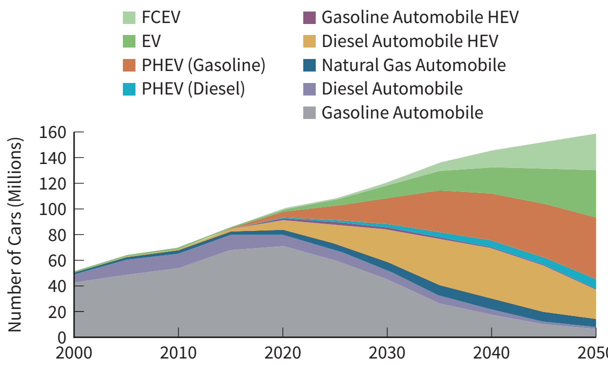
Increasing the energy density of the lithium-ion battery and suppressing the increase in weight

(2) Weight reduction of vehicles

More use of ultra-high-tensile-strength steel plates and resin

Table 1: Carbon dioxide (CO_2) emission limits in major countries and regions

Regulated value	Region	Timeframe 2020	2021	2025	2030
Average CO_2 emission limit for a single automobile (g/km)	Europe	130	95	80	70
	USA	146	—	101	89
	Japan	136	—	114	—
	China	159	—	116	93



* Based on IEA Energy Technology Perspectives 2015 Mobillsing to Accelerate Climate Action [2]

Figure 1: Forecast of scale of global market for automobiles by power source

After 2020, the ratio of EV and PHEV will increase, and by 2050 about 3/4 of all automobiles are expected to be electric-powered cars.

materials, miniaturization, simplification, and integration of machine and circuit components (known as integrated electromechanical components)

(3) Power consumption reduction
Switching from hydraulic actuators to electric actuators; further downsizing and increased efficiency of drive motors

In addition, to shorten the charging time (quick charging), the battery voltage is increased.
Furthermore, to guard against deterioration of the battery, advanced battery monitoring techniques and adoption of solid-state batteries are being developed for the future.
In response to these trends, in addition to motors and batteries, demand for associated semiconductors is also increasing.

2.2 Autonomous, ADAS

In terms of safety, introduction of a new car assessment program (NCAP) and legislation to install safety functions in vehicles are progressing, and the evolution from passive safety to driving support systems, eventually evolving to fully automated driving, is attracting much attention.

In Europe, which is a leader in this field, it is important for each automobile manufacturer to obtain a rank of five stars from Euro NCAP. By 2020 Euro NCAP plans to introduce an automatic brake test that checks for oncoming collisions at intersections, and to add pedestrians and bicycles to test objects by 2023.
Rear and surround monitoring are requirements in the United States under the KT (Kids and Transportation Safety Act) Act. It has been announced that by 2022 all new cars from major manufacturers will be equipped with automatic emergency brakes as standard. Also, the National Highway Traffic Safety Administration (NHTSA) is aiming to mandate by 2022 the installment of Autonomous Emergency Braking (AEB).
Japan's JNCAP provides ranks for safety, including those necessary for the protection and support of elderly people.

For automated driving, the functional definitions are being discussed at the Working Party 29 of the United Nations. In Japan, the Cabinet Office is managing the research of automated driving systems as a Strategic Innovation Promotion Program (SIP) activity.

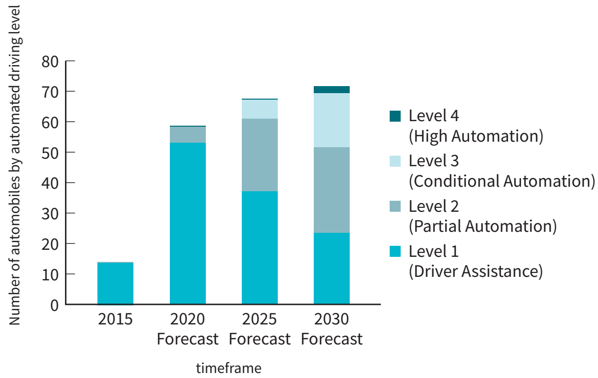
Table 2[(3)] shows the definition of levels of automated driving defined by the Society of Automobile Engineers (SAE), which is recognized as a common concept throughout the world today.

Figure 2[(4)] shows the forecast number of automobiles with automated driving systems by level in the world market. The adoption ratio of ADAS (Level 1 or higher) reaches about 60% of all cars after 2020, but it is predicted that Level 2 class will gradually become mainstream. Automated operation (Level 3 or higher) starts in limited environments around 2020, and it is predicted that mainstream adoption will start from around 2025 to 2030. In order

Table 2: Definition of automated driving levels as classified by SAE J3016 standard of Society of Automotive Engineers (SAE) International

Level	Definition	Safety execution
Level 1 (Driver Assistance)	Driving mode- specific execution by a driver assistance system	Driver
Level 2 (Partial Automation)	Part-time or driving mode-dependent execution by one or more driver assistance systems	Driver
Level 3 (Conditional Automation)	Driving mode-specific performance by an automated driving system of all aspects - human driver does respond appropriately to request to intervene	Driver and system
Level 4 (High Automation)	Driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task	System
Level 5 (Full Automation)	Full-time performance by automated driving systems of all aspects	System

*Based on Strategic Conference for the Advancement of Utilizing Public and Private Sector Data, Strategic Headquarters for the Advanced Information and Telecommunications Network Society : Public-Private ITS Initiative/Roadmap 2017 [(3)]



* Based on Yano Research Institue: Automated Driving System Market 2016 - R&D Trends in Tier 1 / Automakers [(4)]

Figure 2: Forecast of scale of global market for automobiles by automated driving level

ADAS adoption will reach about 60% in 2020 but automated driving at level 3 or higher will also become commonplace.

to realize this, not only are improvements in object recognition and associated judgment by the car itself important but integration and control using cloud services and infrastructure data access, as well as advances in human-machine interfaces (HMI), will also become crucial.

2.3 Connected

Most of the information used by automobiles, such as control data and infotainment content, is generated and processed inside the car, and data received from outside, such as radio, television, VICS (Vehicle Information and Communication System), beacons, GPS (Global Positioning System), have been limited to broadcasting and navigation data. The exchange of basic data with the outside was performed only in limited situations such as acquisition of log data at a car dealer and rewriting programs by means of the OBD 2 (On-Board Diagnostics 2) interface. Even with the emergence of IoT (Internet of Things), automobiles have been left behind in terms of network connectivity.

However, network connections are becoming an essential requirement owing to the increasing importance of real-time information, the introduction of OTA (Over-The-Air) methods for updating various kinds of vehicle software, and the expansion of smartphone-assisted services. As examples of real-time information used in automobiles, there is infrastructure information such as dynamically updated maps that include road conditions necessary for automated driving and sharing of vehicle-to-vehicle driving information.

For communicating with the outside world, vehicles may use systems such as V2X (Vehicle to X, using the 5.9 GHz band in Europe and North America, 760 MHz band in Japan) and LTE (Long Term Evolution) via smartphones. Increasingly, these systems are built into automobiles in the form of dedicated DCMs (Data Communication Modules). As communication traffic volume with the outside increases and the information sharing and synchronization inside the car grows, the capacity and speed of the in-vehicle LAN having only several megabits/sec using conventional CAN (Controller Area Network) communications is becoming inadequate. Introduction of the Ethernet AVB (Audio Video Bridge), the next-generation in-vehicle LAN, is starting.

Separately, the risks of unauthorized access from outside, such as relay attacks of keyless entry systems, reading the encryption keys of immobilizer systems, hacking impersonation, and falsification of IDs are increasing and the strengthening of security measures is more crucial than ever.

In the case of automobiles, as the entire lifecycle, from the start of development through to commercialization and final disposal, is very long, it is necessary to have a mechanism that can keep up with the changes in communication environments and advances in security attacks for a long period of time.

2.4 Shared

As the value of car ownership declines with the saturation of the number of vehicles in urban areas and automated driving technology advances and becomes commonplace in the future, adoption of car sharing and ride sharing schemes is expected to increase in the future.

As can be seen with the advent of the term "MaaS (Mobility as a Service)", service vendors who had no relations with cars are now entering the market and new business models are being created, such as pricing schemes in accordance with the car usage time.
OEMs (Original Equipment Manufacturer) whose main business domains were manufacturing and sales are now starting to emphasize the service opportunities as well.

3. Technology trends of automotive semiconductors

3.1 Environment: Electric drive using motors

Electric-powered cars and HEVs need to improve driving performance but, as described in Section 2.1, must decrease energy consumption and increase distance coverage by deploying compact, lightweight, and highly efficient systems. A block diagram of a PHEV is shown in **Figure 3**.

In order to achieve both miniaturization and high torque, increases are made in the motor rotation and the control frequency. Therefore, the motor control MCUs (Micro Controller Units) of electric-powered cars and HEV systems need to be quiet and highly efficient, having high-speed control and equipped with a vector control unit capable of controlling a motor with a rotation in excess of 20,000 rpm. Also, as the "driving" function of an automobile, a fail-safe of ASIL (Automotive Safety Integrity Level) D of the ISO 26262 safety standard is required.

Signals of different voltages are exchanged between systems inside electric-powered cars and HEV cars and batteries, increasing the demand for electrically isolated interface devices. One of these is a photocoupler, which couples electrical signals optically and is mainly used for signal communications in the battery monitoring system (BMS) as well as in inverters, DC-DC converters and switches for monitoring the battery voltage inside the BMS.

In addition to the driving section, various efforts to replace current mechanical parts, piping, bearings, etc. used to convey power with motors are ongoing in order to reduce weight. Even for engine-driven vehicles, since the engine cannot provide power during idling-stop moments, it is necessary to support the circulation of cooling water, hydraulic pressure, and fuel with a motor, and various three-phase motors featuring quiet operation (for low-speed rotation, rapid start, noise reduction, etc.) have been developed to meet these goals[5].

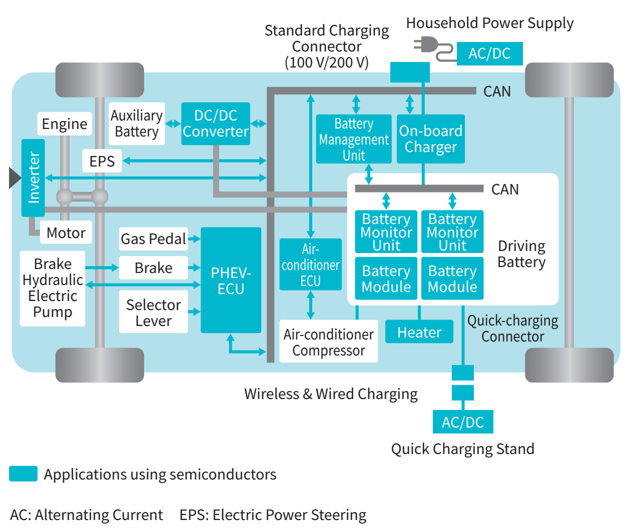


Figure 3: Configuration of plug-in HEV (PHEV)

Compared to today's engine-powered automobiles, there will be substantially more applications using semiconductor products.

Integration technologies for aggregating and miniaturizing power devices are also important, in particular for body systems regarding which there is market demand for products having analog circuits and power semiconductors in a single package for integrated electromechanical systems. In this case, since heat dissipation is a major issue, it becomes necessary to improve the package and connector structures, as well as optimize the chip placement by means of thermal simulation.

Power steering is also evolving from conventional hydraulic systems to motor-assisted systems, but since steering consists of "turning", a basic function of the car, circuit redundancy is required (duplicate, quadruple) to ensure functional safety. A maximum of 22 MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) for driving electric motors for electric power steering (EPS) are mounted in the ECU (Electronic Control Unit). To allow large currents together with miniaturization (which are contradictory requirements), it is necessary to reduce the MOSFETs' "on" resistance.
Modern automobiles control body-related switches and sensors using a BCM (Body Control Module). Consequently, replacement of mechanical relays with semiconductor switches is progressing as well. Mechanical relays have numerous issues, including large current consumption from driving coils, large external form, slow response time, and short life due to mechanical contacts. In the case of semiconductor relays (field-effect transistors and control ICs), it is possible to reduce the size, weight and current consumption, improve responsiveness and extend the operating life.
Various measures are being implemented to improve the electric power efficiency of automobiles, such as the efficiency of audio amplifiers. In addition, along with electrification, new onboard devices such as Vehicle Sound for Pedestrian (VSP) and Active Sound Controller (ASC) are starting to spread.

3.2 Safety: Driving assist

In the field of ADAS and automated driving, many kinds of systems are required and, as shown in **Figure 4**, they are classified according to the need.

Deep learning technology using neural networks that simulate the human brain is attracting attention as a means of integrated judgment and route calculation necessary for automated driving at Level 3 or higher, where mainstream adoption is expected to

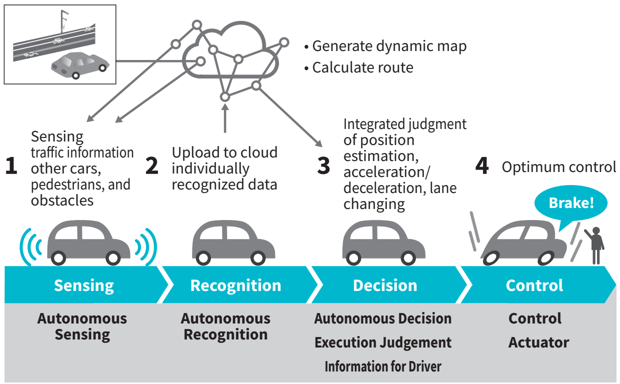


Figure 4: Requirements for automated driving

The main processes of automated driving consist of sensing, recognition, judgement and control. Many systems are assigned tasks based on the requirements.

occur. In order to realize this, it is expected that high-performance manycore processors incorporating a large number of GPUs (Graphics Processing Units), CPUs, DSPs (Digital Signal Processors), etc. will become mainstream. For example, since the module of the front monitoring system is usually installed on the backside of the center rear-view mirror, the temperature environment will be harsh. The amount of data processing increases with the number of pixels and the increase in the frame rate. It will also become necessary to execute multiple recognition applications at the same time. To solve these problems, it is necessary to have an architecture that can flexibly deal with diverse applications such as image processing and recognition processing at high speed and low power consumption[6].

Also, to realize automated driving, a high-precision 3D (three-dimensional) map (obstacle map) obtained by integrated judgment from cloud service data and external data, autonomously sensed data are necessary to create a route and control the driving. As a means of autonomous sensing, sensor fusion combining millimeter-wave radar, LiDAR (Light Detection and Ranging), sonar and/or others will be required in addition to image recognition by cameras. In particular, for highly accurate 3D map generation, it is expected that the use of LiDAR will increase. Currently, the LiDAR scans and beams the laser mechanically and receives the reflections with an APD (Avalanche Photo Diode) in the majority of cases but, in order to achieve mainstream adoption, the LiDAR should be a solid-state unit without any mechanical moving parts, and the light-receiving element should be a SiPM (Silicon Photo Multiplier) device.

3.3 Information: High-speed network communications

Until now, other than ETC (Electronic Toll Collection system) and remote keyless entry systems, Bluetooth®-based applications such as content playback and hands-free voice communications for car audio and smartphones were the main usages. However, there are other usage trends such as acquisition and management of in-vehicle information, including battery status and driving data.

High-speed networks based on the in-vehicle Ethernet AVB standard and next-generation TSN (Time Sensitive Network) are used not only for transmission of image data from cameras, but also for V2X communications, linkage with smartphones, cloud services and infrastructure data using vehicle-mounted communication modules. These interfacing functions will become mandatory items.

In the future, the HMI function will become important. Sensor status and data from cloud services will be sent to the driver using voice synthesis, and high-resolution images and user interfaces with voice and gesture input will all contribute to increasing the data traffic inside the car.

3.4 Efficient development and focus on reliability

Efficiency is an important aspect of development, and model-based development is becoming standard. In terms of quality and reliability, the design-in of quality and reliability from the initial design and development phase is becoming increasingly important in order to respond to the needs of miniaturization and higher integration.

4. Future outlook

The spread of car sharing and ride sharing will not only help the standardization of automobile platforms and architectures but will, in addition to promoting new cars, also encourage incremental updating of automobile functions. The application of AI and big data is expected to progress, but the balance between cloud-side and edge-side processing will depend on the amount of data as well as the adoption rate of 5G (fifth-generation mobile communication system). This includes the evolution of the communications environment and the processing capability of the edge functions. In addition, security technology is becoming increasingly important with the adoption of OTA updates, the recording of vehicle conditions during automated driving (black box), protection of personal data during resale/disposal, and so forth. Besides the development of the secure technology itself, new issues such as the management of data need to be addressed. Furthermore, in terms of functional safety, requirements from the standpoint of safety and robustness against external attacks are being added.

5. Conclusion

The environment in which automobiles operate and the technical trends of automotive semiconductors were described.
By developing various semiconductor technologies that contribute to CASE, we will continue to offer semiconductor technologies that comprehensively assist human sight and related driving senses, toward the realization of automated driving.

References

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