International Journal of Advanced Technology in Engineering and Science
Vol. No. 10, Issue No. 01, January 2022
www.ijates.com
ijates
ISSN 2348 - 7550

VLSI Technology for Future Automotive and Mobility System

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ABSTRACT

Since the first introduction of microprocessors in automobiles in the 1970's, the world has witnessed their dramatic growth as well as their contribution to all aspects of vehicle performance. As the global demand for personal mobility continues to grow, the automotive industry needs to accelerate the development of solutions to social issues such as environment, energy security, traffic accidents, and urban traffic congestion.

To address these issues, Most of the OEMs seek out the ultimate goal of "Zero Emission" and "Zero Fatalities" through vehicle electrification and vehicle intelligence. The electric vehicle is a symbol of electrification, where components are fully electrically-powered and controlled. Autonomous driving technologies, such as advanced sensing, dynamic driving context interpretation, vehicle maneuver planning and controls, exemplify vehicle intelligence.

This paper provides an overview of the contribution of VLSI (Very Large Scale Integration) to enhancing vehicle electrification and vehicle intelligence, as well as the perspectives for future mobility systems.

I. INTRODUCTION

Since the first introduction of microcontroller units (MCU) into automobile engine control, the performance of engines has significantly evolved in terms of power, fuel efficiency and emissions.

In addition to engine controls, electronics have seen a wave of expanded functions. Today, the number of electrical control units (ECU) in automobiles has increased to over fifty, Thus reaching ~40% of Total Car Cost as shown in Fig. 1

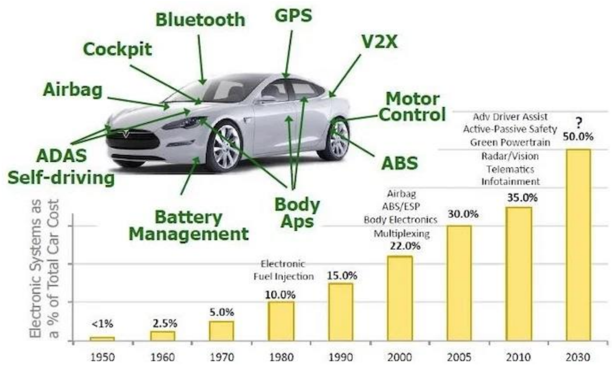

Fig. 1. Evolution of ECUs and their Cost share

One hundred and ten years has passed since the advent of mass-production of automobiles. Current annual production volumes already exceed eighty million, and automotive markets are expected to grow even further. However, with the progress of motorization, automotive systems face serious social issues, such as energy security, global warming, urban congestion, and traffic accidents. Fig. 2 shows the increasing trend in energy consumption [1].

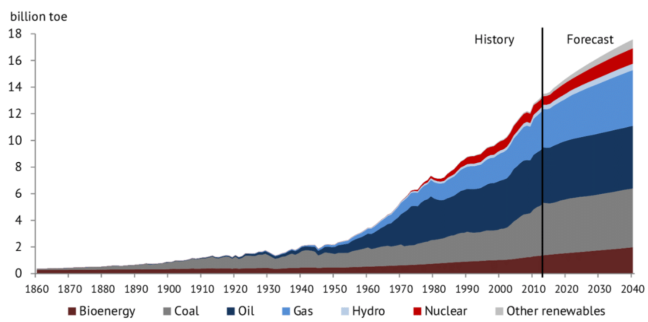

Fig. 2. Energy Consumption Scenario

Energy consumption has tripled in thirty years, yet most sources of energy are still based on fossil fuels. According to IPCC (Intergovernmental Panel on Climate Change), global mean surface temperature has increased about 1 degree Celsius since pre-industrial times caused by anthropogenic greenhouse gas (GHG) emissions [2]. Fig. 3 shows the trend in global average temperature since 1894. As for urban congestion, we estimate that the resulting global financial loss has reached over 500 billion dollars. Lastly, the World Health Organization (WHO) reported that there were 1.35 million road traffic deaths globally in 2018 [3].

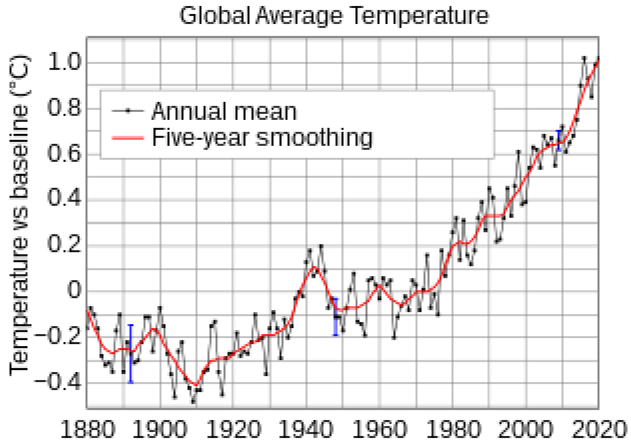

Fig. 3 Global Average Temperature [2]

Every Automotive OEM and it's System Supplier believes that the key to solving these issues is "Vehicle Electrification" and "Vehicle Intelligence".

II. VEHICLE ELECTRIFICATION

Vehicle electrification has potential to accelerate the reduction of CO2 by leveraging energy efficiency (Fig. 4). In addition, electrification encompasses a diverse array of energy sources, for example, electricity and hydrogen generated from fossil fuels, solar, wind, nuclear, and biomass. On the other hand, conventional internal combustion engine vehicles (ICEV) and hybrid vehicles (HV) are only able to use oil as an energy source (Fig. 5). To reduce CO2 levels, we need to reduce the use of fossil fuels.

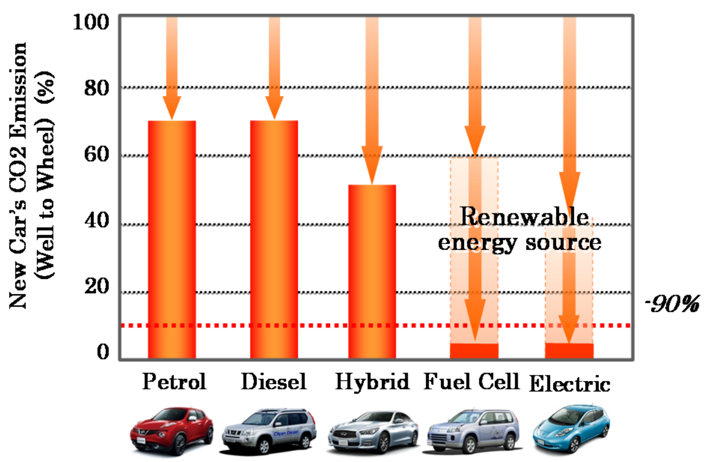

Fig. 4. Opportunities to reduce CO2 emissions

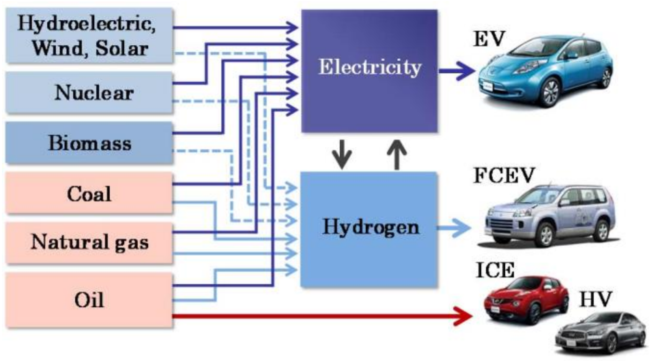

Fig. 5. Energy source diversity by vehicle type

Therefore, the new Automotive Powertrain strategy emphasizes the conversion from fossil fuels to renewable energy sources. An embodiment of this mindset, Most of the Global OEMs released all-electric vehicles (EV) and some of the Globally best-selling EVs in 2021 are provided for reference [4]. The key devices of electrification are the inverter and battery controller, which will be the key components in the new frontier of LSI (Table 1) as represented in (Fig. 6) EV System.

Table 1. Key devices of electrification

Key Device	Function
Inverter	● Output Control ● Regeneration Control
Battery Controller	● Status Monitoring ● Protection ● Failsafe

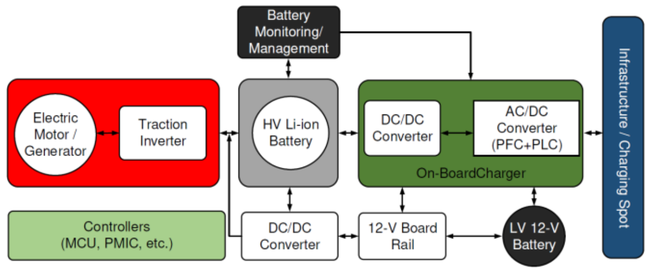

Fig. 6 Blocks within an EV System [5]

The Key components, in an EV system that requires miniaturisation, higher efficiency, lower power dissipation and cost reduction through VLSI are

1. Power Management IC (PMIC)
2. Microcontroller (MCU)
3. High Power IGBTs or SiC MOSFETs
4. Sensing & Monitoring blocks
5. Various Protection & Isolation circuits

The Simplified Block diagram of this whole system is represented in Fig. 7. The switches are controlled via the MCU and isolated gate drivers for the high side (HS) and low side (LS) of the inverter leg. The PWM signals are commonly generated using the space vector modulation (SVM) scheme. As the motor operates, the voltage, current and position signals are sensed and fed back to the controller to modify the modulation of the inverter. One such feedback method is field oriented control (FOC).
A good modulation scheme, fast feedback and accurately sensed signals are required for efficient motoring [5].

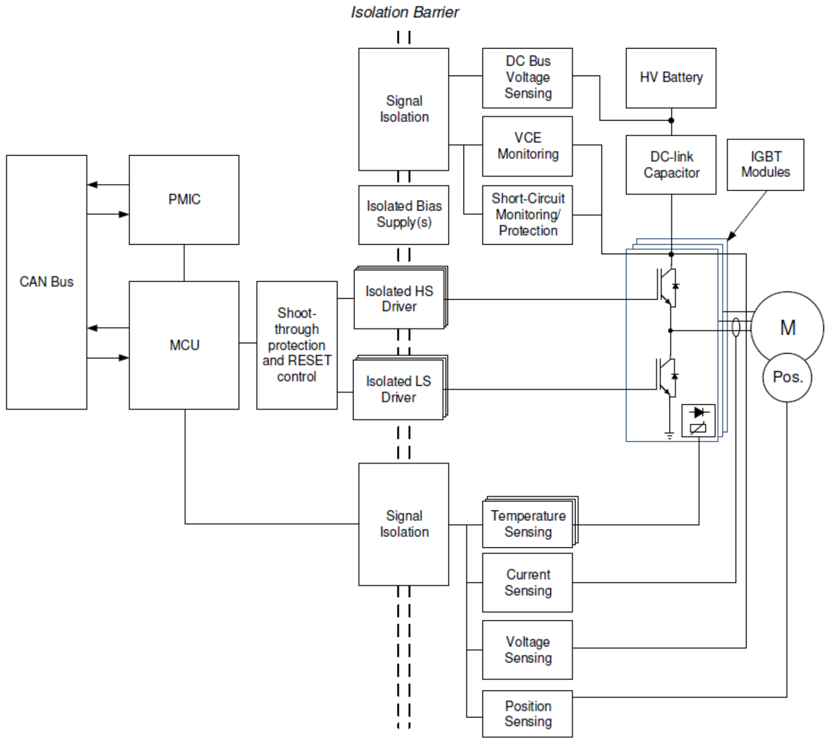

Fig. 7 EV Inverter Block Diagram [5]

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III. VEHICLE INTELLIGENCE

Reports show that more than 90% of traffic accidents are caused by the driver [6]. To aid the driver and reduce human error, more than 20 years ago, OEMs started development of the "Safety Shield" concept whereby the vehicle leverages various barriers, from normal driving to post-accident, to provide continuous support against dangerous situations. The result of these efforts includes some groundbreaking technologies, such as (Fig. 8)

1. Around View Monitor
2. Lane Departure Prevention
3. Back-up Collision Intervention
4. Forward Emergency Braking
5. Blind spot detection etc.,

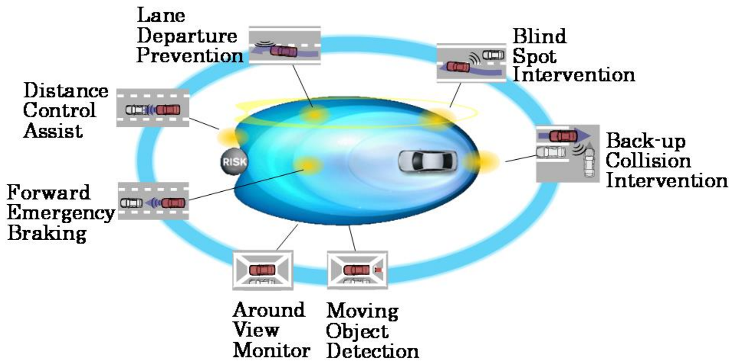

Fig. 8. All-around SAFETY SHIELD technologies

To further improve safety, OEMs are progressively launching even more autonomous driving technologies to enable safe autonomous driving in a single lane on congested highways in the coming years. This will include risk-avoidance and lane-changing functions, which facilitate driving on multiple-lane roads.

For autonomous driving, the core technology functions to support or replace the driver's actions include sensing, cognition, decision, and actuation by on-board systems. Fig. 9 shows the on-board cameras, sensors and actuators required for autonomous diving.

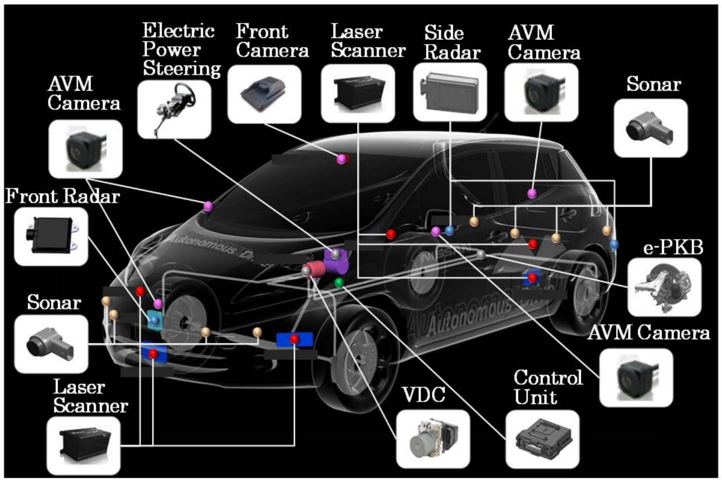

Fig. 9. Key devices for autonomous driving

Needless to say, a “brain,” mapping out a driving plan, is needed for processing the information from various sensors, predicting the behavior of surrounding traffic, and deciding the next actions.

In addition to these four core functions, an evolution of supporting technologies, such as human machine interface (HMI), map, connectivity and E/E architecture, is necessary. Positioning accuracy required for driving in urban areas is reported to be about 20 to 30 cm. Therefore, navigation maps must be so precise that they are on a three-dimensional level.

Additionally, to support unexpected situations that may arise during autonomous driving, dynamic information, such as weather and traffic conditions, should be reflected in real time.

Furthermore, over-the-air (OTA) updates would be necessary to immediately address changes in the environment such as traffic regulations. Because of the connection with the outside network, the on-board electrical/electronic architecture (E/E architecture) must have a security system.Lastly, a further explanation of the details of human machine interface (HMI) is needed. Autonomous driving systems would not completely replace the driver. The driver must still take full driving responsibility. This is why HMI is imperative for autonomous driving. The system should be designed such that it requires relatively little eye movement and the driver is fully aware of the vehicle’s behavior at all times.
Full-TFT meter consoles with 3D graphics and heads-up display (HUD) systems, exhibiting higher CPU and GPU performance than conventional displays/cockpits (Table 2) are required to realize full communication between the driver and the vehicle.

Table 2. Requirements for HMI

Description	Present Vehicles	Autonomous Vehicles
Cockpit type	Analog/Digital meter display	Full TFT cockpit display
CPU	100 MHz	2 GHz
Memory	4 MB	4 GB
GPU	No 3D graphics	3D graphics

IV. INTELLIGENT MOBILITY

In addition to vehicle electrification and vehicle intelligence, OEMs believe that connectivity between vehicles and social infrastructures will be imperative.

One example of the connectivity with social infrastructures is shown in Fig. 10. Today, in the Hawaiian island of Maui, the supply of electricity by wind power exceeds demand during nighttime and early morning hours.

In order to solve the mismatch between supply and demand, several hundred Nissan LEAFs are participating in test studies to charge on-board batteries when supply exceeds demand and discharge to the grid during peak demand hours [7]. In addition, Hawaii and the U.S. The Department of Energy reaffirmed their commitment to the clean energy initiative in 2014, which leads the way in eliminating the dependence on oil by setting the goal of achieving 100% renewable energy by 2045 [7]. This surplus in electricity should continue to vastly grow, therefore we estimate that it is possible to shift the supply-demand peak using 16,000 Nissan LEAFs, which is equivalent to one-third of all passenger vehicles in Maui.

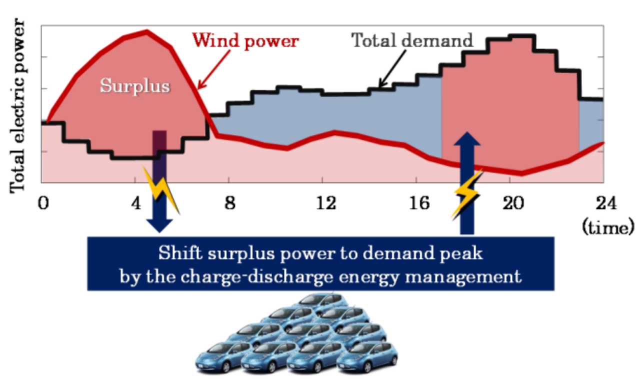

Fig. 10. Trend of supply and demand of electricity in the Hawaiian island of Maui

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ISSN 2348 - 7550

Another example of the link with social infrastructure is traffic control. Traffic congestion is often the result of a chain of events caused by reduced speeds from variations in the grade of the highway. As vehicles are forced to get closer together, abrupt speed changes cause shock waves to form in the traffic stream, rippling backward and causing even more vehicles to slow down.

An effective way to avoid this type of traffic congestion would be to control the speed of each vehicle as well as the distance between them using a "*vehicle to infrastructure*" (V2I) system (Fig. 11).

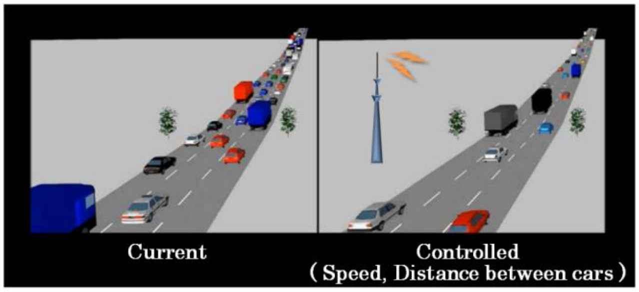

Fig. 11. Simulation of traffic on the Tomei Expressway in Yamato city, Japan

V. SUMMARY

This paper provides an overview of intelligent mobility realized by vehicle electrification and vehicle intelligence. In addition, it suggests new application opportunities for VLSI, such as electric powertrain, battery, sensors, camera, AI and connected vehicle management systems. LSIs must be optimized to vehicle application in response to growing automotive demand.

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