4 Embedded Systems—Application- and Domain-Specific

LEARNING OBJECTIVES

- ✓ *Illustrate the domain and application specific aspect of embedded systems with examples*
- ✓ *Know the presence of embedded systems in automotive industry*
- ✓ *Learn about High Speed Electronic Control Units (HECUs) and Low Speed Electronic Control Units (LECUs) employed in automotive applications*
- ✓ *Learn about the Controller Area Network (CAN), Local Interconnect Network (LIN) and Media Oriented System Transport (MOST) communication buses used in automotive applications*
- ✓ *Know the semiconductor chip providers, tools and platform providers and solution providers for automotive embedded applications*

As mentioned in the previous chapter on the characteristics of embedded systems, embedded systems are application and domain specific, meaning; they are specifically built for certain applications in certain domains like consumer electronics, telecom, automotive, industrial control, etc. In general purpose computing, it is possible to replace a system with another system which is closely matching with the existing system, whereas it is not the case with embedded systems. Embedded systems are highly specialised in functioning and are dedicated for a specific application. Hence it is not possible to replace an embedded system developed for a specific application in a specific domain with another embedded system designed for some other application in some other domain. The following sections are intended to give the readers some idea on the application and domain specific characteristics of embedded systems.

4.1 WASHING MACHINE—APPLICATION-SPECIFIC EMBEDDED SYSTEM

People experience the power of embedded systems and enjoy the features and comfort provided by them, but they are totally unaware or ignorant of the intelligent embedded players working behind the products providing enhanced features and comfort. Washing machine is a typical example of an embedded system providing extensive support in home automation applications (Fig. 4.1).

As mentioned in an earlier chapter, an embedded system contains sensors, actuators, control unit and application-specific user interfaces like keyboards, display units, etc. You can see all these components in a washing machine if you have a closer look at it. Some of them are visible and some of them may be invisible to you.

The actuator part of the washing machine consists of a motorised agitator, tumble tub, water drawing pump and inlet valve to control the flow of water into the unit. The sensor part consists of the water temperature sensor, level sensor, etc. The control part contains a microprocessor/controller based board with interfaces to the sensors and actuators. The sensor data is fed back to the control unit and the control unit generates the necessary actuator outputs. The control unit also provides connectivity to user interfaces like keypad for setting the washing time, selecting the type of material to be washed like light, medium, heavy duty, etc. User feedback is reflected through the display unit and LEDs connected to the control board. The functional block diagram of a washing machine is shown in Fig. 4.2.

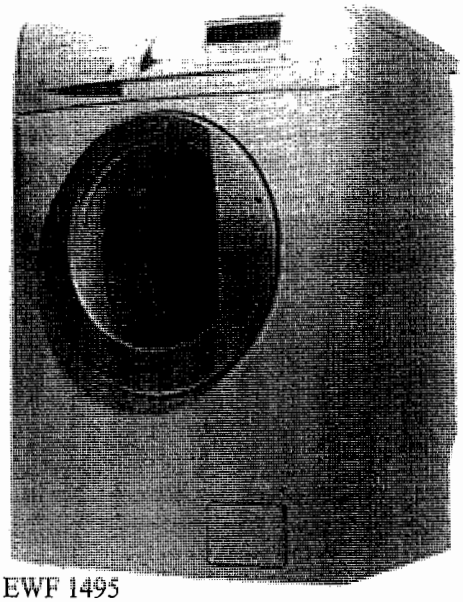
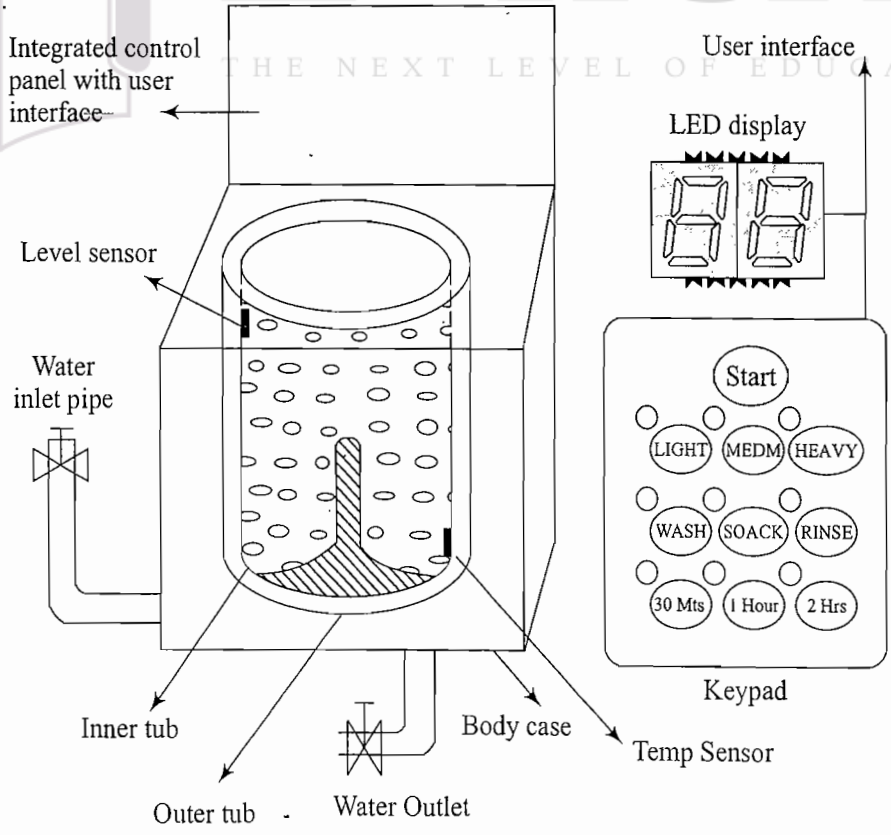


Fig. 4.1 **Washing Machine – Typical example of an embedded system**
(Photo courtesy of Electrolux Corporation (www.electrolux.com/au))



Picture not to scale

Fig. 4.2 **Washing machine – Functional block diagram**

Washing machine comes in two models, namely, top loading and front loading machines. In top loading models the agitator of the machine twists back and forth and pulls the cloth down to the bottom of the tub. On reaching the bottom of the tub the clothes work their way back up to the top of the tub where the agitator grabs them again and repeats the mechanism. In the front loading machines, the clothes are tumbled and plunged into the water over and over again. This is the first phase of washing.

In the second phase of washing, water is pumped out from the tub and the inner tub uses centrifugal force to wring out more water from the clothes by spinning at several hundred Rotations Per Minute (RPM). This is called a '*Spin Phase*'. If you look into the keyboard panel of your washing machine you can see three buttons namely* *Wash*, *Spin* and *Rinse*. You can use these buttons to configure the washing stages. As you can see from the picture, the inner tub of the machine contains a number of holes and during the spin cycle the inner tub spins, and forces the water out through these holes to the stationary outer tub from which it is drained off through the outlet pipe.

It is to be noted that the design of washing machines may vary from manufacturer to manufacturer, but the general principle underlying in the working of the washing machine remains the same. The basic controls consist of a timer, cycle selector mechanism, water temperature selector, load size selector and start button. The mechanism includes the motor, transmission, clutch, pump, agitator, inner tub, outer tub and water inlet valve. Water inlet valve connects to the water supply line using at home and regulates the flow of water into the tub.

The integrated control panel consists of a microprocessor/controller based board with I/O interfaces and a control algorithm running in it. Input interface includes the keyboard which consists of wash type selector namely* *Wash*, *Spin* and *Rinse*, cloth type selector namely* *Light*, *Medium*, *Heavy duty* and washing time setting, etc. The output interface consists of LED/LCD displays, status indication LEDs, etc. connected to the I/O bus of the controller. It is to be noted that this interface may vary from manufacturer to manufacturer and model to model. The other types of I/O interfaces which are invisible to the end user are different kinds of sensor interfaces, namely, water temperature sensor, water level sensor, etc. and actuator interface including motor control for agitator and tub movement control, inlet water flow control, etc.

4.2 AUTOMOTIVE – DOMAIN-SPECIFIC EXAMPLES OF EMBEDDED SYSTEM

The major application domains of embedded systems are consumer, industrial, automotive, telecom, etc., of which telecom and automotive industry holds a big market share.

Figure 4.3 gives an overview of the various types of electronic control units employed in automotive applications.

4.2.1 Inner Workings of Automotive Embedded Systems

Automotive embedded systems are the one where electronics take control over the mechanical systems. The presence of automotive embedded system in a vehicle varies from simple mirror and wiper controls to complex air bag controller and antilock brake systems (ABS). Automotive embedded systems are normally built around microcontrollers or DSPs or a hybrid of the two and are generally known as Electronic Control Units (ECUs). The number of embedded controllers in an ordinary vehicle varies

*Name may vary depending on the manufacturer.

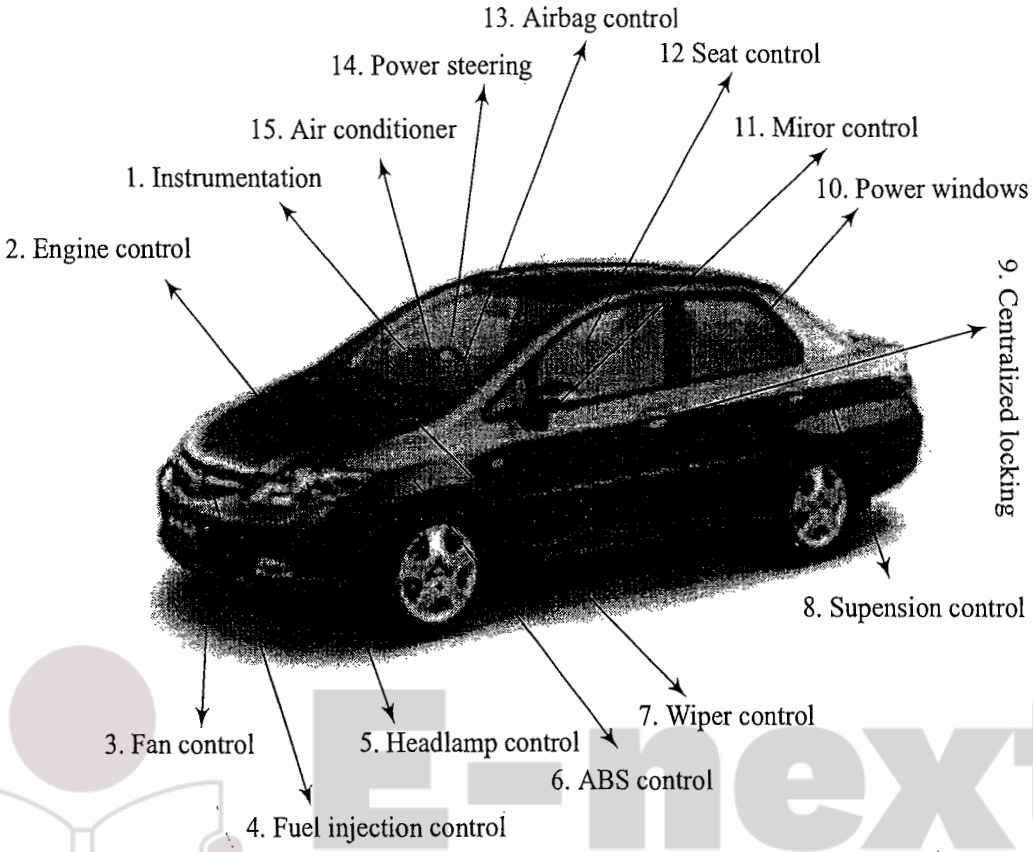


Fig. 4.3 **Embedded system in the automotive domain**
(Photo courtesy of Honda Siel Car India (www.hondacarindia.com))

from 20 to 40 whereas a luxury vehicle like Mercedes S and BMW 7 may contain 75 to 100 numbers of embedded controllers. Government regulations on fuel economy, environmental factors and emission standards and increasing customer demands on safety, comfort and infotainment forces the automotive manufactures to opt for sophisticated embedded control units within the vehicle. The first embedded system used in automotive application was the microprocessor based fuel injection system introduced by Volkswagen 1600 in 1968.

The various types of electronic control units (ECUs) used in the automotive embedded industry can be broadly classified into two–High-speed embedded control units and Low-speed embedded control units.

4.2.1.1 High-speed Electronic Control Units (HECUs) High-speed electronic control units (HECUs) are deployed in critical control units requiring fast response. They include fuel injection systems, antilock brake systems, engine control, electronic throttle, steering controls, transmission control unit and central control unit.

4.2.1.2 Low-speed Electronic Control Units (LECUs) Low-Speed Electronic Control Units (LECUs) are deployed in applications where response time is not so critical. They generally are built around low cost microprocessors/microcontrollers and digital signal processors. Audio controllers, passenger and driver door locks, door glass controls (power windows), wiper control, mirror control, seat control systems, head lamp and tail lamp controls, sun roof control unit etc. are examples of LECUs.

4.2.2 Automotive Communication Buses

Automotive applications make use of serial buses for communication, which greatly reduces the amount of wiring required inside a vehicle. The following section will give you an overview of the different types of serial interface buses deployed in automotive embedded applications.

4.2.2.1 Controller Area Network (CAN) The CAN bus was originally proposed by Robert Bosch, pioneer in the Automotive embedded solution providers. It supports medium speed (ISO11519-class B with data rates up to 125 Kbps) and high speed (ISO11898 class C with data rates up to 1Mbps) data transfer. CAN is an event-driven protocol interface with support for error handling in data transmission. It is generally employed in safety system like airbag control; power train systems like engine control and Antilock Brake System (ABS); and navigation systems like GPS. The protocol format and interface application development for CAN bus will be explained in detail in another volume of this book series.

4.2.2.2 Local Interconnect Network (LIN) LIN bus is a single master multiple slave (up to 16 independent slave nodes) communication interface. LIN is a low speed, single wire communication interface with support for data rates up to 20 Kbps and is used for sensor/actuator interfacing. LIN bus follows the master communication triggering technique to eliminate the possible bus arbitration problem that can occur by the simultaneous talking of different slave nodes connected to a single interface bus. LIN bus is employed in applications like mirror controls, fan controls, seat positioning controls, window controls, and position controls where response time is not a critical issue.

4.2.2.3 Media-Oriented System Transport (MOST) Bus The Media-oriented system transport (MOST) is targeted for automotive audio/video equipment interfacing, used primarily in European cars. A MOST bus is a multimedia fibre-optic point-to-point network implemented in a star, ring or daisy-chained topology over optical fibre cables. The MOST bus specifications define the physical (electrical and optical parameters) layer as well as the application layer, network layer, and media access control. MOST bus is an optical fibre cable connected between the Electrical Optical Converter (EOC) and Optical Electrical Converter (OEC), which would translate into the optical cable MOST bus.

4.2.3 Key Players of the Automotive Embedded Market

The key players of the automotive embedded market can be visualised in three verticals namely, silicon providers, solution providers and tools and platform providers.

4.2.3.1 Silicon Providers Silicon providers are responsible for providing the necessary chips which are used in the control application development. The chip may be a standard product like microcontroller or DSP or ADC/DAC chips. Some applications may require specific chips and they are manufactured as Application Specific Integrated Chip (ASIC). The leading silicon providers in the automotive industry are:

Analog Devices (www.analog.com)**:** Provider of world class digital signal processing chips, precision analog microcontrollers, programmable inclinometer/accelerometer, LED drivers, etc. for automotive signal processing applications, driver assistance systems, audio system, GPS/Navigation system, etc.

Xilinx (www.xilinx.com)**:** Supplier of high performance FPGAs, CPLDs and automotive specific IP cores for GPS navigation systems, driver information systems, distance control, collision avoidance, rear seat entertainment, adaptive cruise control, voice recognition, etc.

Atmel (www.atmel.com)**:** Supplier of cost-effective high-density Flash controllers and memories. Atmel provides a series of high performance microcontrollers, namely, ARM®[1], AVR®[2], and 80C51. A wide range of Application Specific Standard Products (ASSPs) for chassis, body electronics, security, safety and car infotainment and automotive networking products for CAN, LIN and FlexRay are also supplied by Atmel.

Maxim/Dallas (www.maxim-ic.com)**:** Supplier of world class analog, digital and mixed signal products (Microcontrollers, ADC/DAC, amplifiers, comparators, regulators, etc), RF components, etc. for all kinds of automotive solutions.

NXP semiconductor (www.nxp.com)**:** Supplier of 8/16/32 Flash microcontrollers.

Renesas (www.renesas.com)**:** Provider of high speed microcontrollers and Large Scale Integration (LSI) technology for car navigation systems accommodating three transfer speeds: high, medium and low.

Texas Instruments (www.ti.com)**:** Supplier of microcontrollers, digital signal processors and automotive communication control chips for Local Inter Connect (LIN) bus products.

Fujitsu (www.fmal.fujitsu.com)**:** Supplier of fingerprint sensors for security applications, graphic display controller for instrumentation application, AGPS/GPS for vehicle navigation system and different types of microcontrollers for automotive control applications.

Infineon (www.infineon.com)**:** Supplier of high performance microcontrollers and customised application specific chips.

NEC (www.nec.co.jp)**:** Provider of high performance microcontrollers.

There are lots of other silicon manufactures which provides various automotive support systems like power supply, sensors/actuators, optoelectronics, etc. Describing all of them is out of the scope of this book. Readers are requested to use the Internet for finding more information on them.

4.2.3.2 Tools and Platform Providers Tools and platform providers are manufacturers and suppliers of various kinds of development tools and Real Time Embedded Operating Systems for developing and debugging different control unit related applications. Tools fall into two categories, namely embedded software application development tools and embedded hardware development tools. Sometimes the silicon suppliers provide the development suite for application development using their chip. Some third party suppliers may also provide development kits and libraries. Some of the leading suppliers of tools and platforms in automotive embedded applications are listed below.

ENEA (www.enea.com)**:** Enea Embedded Technology is the developer of the OSE Real-Time operating system. The OSE RTOS supports both CPU and DSP and has also been specially developed to support multi-core and fault-tolerant system development.

The MathWorks (www.mathworks.com)**:** It is the world's leading developer and supplier of technical software. It offers a wide range of tools, consultancy and training for numeric computation, visualisation, modelling and simulation across many different industries. MathWork's breakthrough product is MATLAB–a high-level programming language and environment for technical computation and numerical analysis. Together MATLAB, SIMULINK, Stateflow and Real-Time Workshop provide top quality tools for data analysis, test & measurement, application development and deployment, image processing and development of dynamic and reactive systems for DSP and control applications.

[1] ARM® is the registered trademark of ARM Holdings.

[2] AVR® is the registered trademark of Atmel Corporation.

Keil Software (www.keil.com)**:** The Integrated Development Environment Keil Microvision from Keil software is a powerful embedded software design tool for 8051 & C166 family of microcontrollers.

Lauterbach (http://www.lauterbach.com/)**:** It is the world's number one supplier of debug tools, providing support for processors from multiple silicon vendors in the automotive market.

ARTiSAN (www.artisansw.com)**:** Is the leading supplier of collaborative modelling tools for requirement analysis, specification, design and development of complex applications.

Microsoft (www.microsoft.com)**:** It is a platform provider for automotive embedded applications. Microsoft's WindowsCE is a powerful RTOS platform for automotive applications. Automotive features are included in the new WinCE Version for providing support for automotive application developers.

4.2.3.3 Solution Providers Solution providers supply OEM and complete solution for automotive applications making use of the chips, platforms and different development tools. The major players of this domain are listed below.

Bosch Automotive (www.boschindia.com)**:** Bosch is providing complete automotive solution ranging from body electronics, diesel engine control, gasoline engine control, powertrain systems, safety systems, in-car navigation systems and infotainment systems.

DENSO Automotive (www.globaldensoproducts.com)**:** Denso is an Original Equipment Manufacturer (OEM) and solution provider for engine management, climate control, body electronics, driving control & safety, hybrid vehicles, embedded infotainment and communications.

Infosys Technologies (www.infosys.com)**:** Infosys is a solution provider for automotive embedded hardware and software. Infosys provides the competitive edge in integrating technology change through cost-effective solutions.

Delphi (www.delphi.com)**:** Delphi is the complete solution provider for engine control, safety, infotainment, etc., and OEM for spark plugs, bearings, etc.

……and many more. The list is incomplete. Describing all providers is out of the scope of this book.

Summary

- ✓ Embedded systems designed for a particular application for a specific domain cannot be replaced with another embedded system designed for another application for a different domain
- ✓ Consumer, industrial, automotive, telecom, etc. are the major application domains of embedded systems. Telecom and automotive industry are the two segments holding a big market share of embedded systems
- ✓ Automotive embedded systems are normally built around microcontrollers or DSPs or a hybrid of the two and are generally known as Electronic Control Units (ECUs)
- ✓ High speed Electronic Control Units (HECUs) are deployed in critical control units requiring fast response, like fuel injection systems, antilock brake system, etc.
- ✓ Low speed Electronic Control Units (LECUs) are deployed in applications where response time is not so critical. They are generally built around low cost microprocessors/microcontrollers and digital signal processors. Audio controllers, passenger and driver door locks, door glass controls, etc., are examples for LECUs.
- ✓ Automotive applications use serial buses for communication. Controller Area Network (CAN), Local Interconnect Network (LIN), Media Oriented System Transport (MOST) bus, etc. are the important automotive communication buses.

- ✓ CAN is an event driven serial protocol interface with support for error handling in data transmission. It is generally employed in safety system like airbag control, powertrain systems like engine control and Antilock Brake Systems (ABS).
- ✓ LIN bus is a single master multiple slave (up to 16 independent slave nodes) communication interface. LIN is a low speed, single wire communication interface with support for data rates up to 20Kbps and is used for sensor/actuator interfacing.
- ✓ The Media Oriented System Transport (MOST) bus is targeted for automotive audio video equipment interfacing. MOST bus is a multimedia fibre-optic point-to-point network implemented in a star, ring or daisy-chained topology over optical fibres cables
- ✓ The key players of the automotive embedded market can be classified into 'Silicon Providers', 'Tools and Platform Providers' and 'Solution Providers'

Keywords

ECU : Electronic Control Unit. The generic term for the embedded control units in automotive application
HECU : High-speed Electronic Control Unit. The high-speed embedded control unit deployed in automotive applications
LECU : Low-speed Electronic Control Unit. The low-speed embedded control unit deployed in automotive applications
CAN : Controller Area Network. An event driven serial protocol interface used primarily for automotive applications
LIN : Local Interconnect Network. A single master multiple slave, low speed serial bus used in automotive application
MOST : Media Oriented System Transport Bus. A multimedia fibre-optic point-to-point network implemented in a star, ring or daisy-chained topology over optical fibres cables

Objective Questions

1. In Automotive systems, High-speed Electronic Control Units (HECUs) are deployed in
   (a) Fuel injection systems (b) Antilock brake systems
   (c) Power windows (d) Wiper control (e) Only (a) and (b)
2. In Automotive systems, Low speed electronic control units (LECUs) are deployed in
   (a) Electronic throttle (b) Steering controls (c) Transmission control (d) Mirror control
3. The first embedded system used in automotive application is the microprocessor based fuel injection system introduced by _____ in 1968
   (a) BMW (b) Volkswagen 1600 (c) Benz E Class (d) KIA
4. CAN bus is an event driven protocol for communication. State True or False
   (a) True (b) False
5. Which of the following serial bus is (are) used for communication in Automotive Embedded Applications?
   (a) Controller Area Network (CAN) (b) Local Interconnect Network (LIN)
   (c) Media Oriented System Transport (MOST) bus (d) All of these (e) None of these
6. Which of the following is true about LIN bus?
   (a) Single master multiple slave interface (b) Low speed serial bus
   (c) Used for sensor/actuator interfacing (d) All of these (e) None of these

7. Which of the following is true about MOST bus?
   (a) Used for automotive audio video system interfacing
   (b) It is a fibre optic point-to-point network
   (c) It is implemented in star, ring or daisy-chained topology
   (d) All of these (e) None of these
8. Which of the following is (are) example(s) of Silicon providers for automotive applications?
   (a) Maxim/Dallas (b) Analog Devices (c) Xilinx (d) Atmel
   (e) All of these (f) None of these

Review Questions

1. Explain the role of embedded systems in automotive domain.
2. Explain the different electronic control units (ECUs) used in automotive systems.
3. Explain the different communication buses used in automotive application.
4. Give an overview of the different market players of the automotive embedded application domain.