Najamuz Zaman

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Vehicle Electronics Architecture

1.1 Introduction

Early designs of automobiles used to have very little electrical content with very few electrical parts, a bunch of connectors and a couple of harnesses with simple electrical layouts. There were no microprocessors, or so to speak, no embedded software. As a result of the growing needs and wants of the customer, car manufacturers, government regulations and the availability of the analog, digital and microprocessor based integrated electronics kicked off the successful launch of an internal combustion engine controller; a fairly sophisticated, mission critical, real-time computer located under the hood. The success of engine controller spawned the development of many critical vehicle functions by utilizing the embedded design like automatic transmission and vehicle cruise control. An automatic transmission is an intriguing combination of fluid dynamics, mechanics, electro-magnetic and electronics—managing the power transfer between the engine and the gear train for optimal vehicle motion. The real challenge for this design is the precise control of hydraulic valves and the sensitive torque detection mechanism to select the optimal gear-speed. The cruise control is a function that manages the engine throttle to maintain a constant vehicle speed selected by the user. An advanced version of cruise control has been recognized as an adaptive cruise control that adapts to the speed of a slow-moving vehicle ahead of you by automatically reducing your vehicle speed to maintain a safer distance. The radar detection based sensors are used to measure the vehicle speed moving ahead of you. An intriguing feature of auto parallel park assist is a glowing example of incorporating electronics, electric motor steering, and object detection sensors. The function of auto parallel park assist is an

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impressive feature in a manner that it assists the driver to do parallel parking in a vacant, even tightly-spaced parking spot by relinquishing the steering wheel control to the embedded controller, the only example of hands-free reversing. At the end of the vehicle maneuvers, you will find yourself safely parked between the cars.

1.2 Instrument Cluster

This is the most visible device of any vehicle. It displays information such as the vehicle speed, fuel quantity, engine temperature, engine rpm and gear position, among other features. It used to be a 'dumb' display with dial-pointers coupled mechanically to the mechanical sensors—but today—it has turned into an intelligent embedded device that has a direct 'hot line' to the engine controller, and a few other modules. It conveys critical early warnings and cautions to the driver by means of dial pointers, visual displays, audible tones and telltales. Added features include, but are not limited to: seat-belt status, fuel consumption computations, oil change warnings, tire pressure information, multiple trip mileage logging, and operational status monitoring of other vehicle systems.

1.3 Heating and Cooling

The heating and air conditioning in a typical vehicle requires an engine driven air-conditioning compressor pump and a speed-controlled blower motor to distribute warm and cool air through air outlet registers. Is there a reason for electronics or embedded design to be added to this simple application? The answer is both yes and no, depending on the type of vehicle or manufacturer. Some HVAC (Heating Ventilating & Air Conditioning) systems are simple and do not require embedded controller, but some require an embedded controller to provide better system performance, enhanced temperature control, additional informed-display, system self-tests, diagnostics, troubleshooting features and more.

1.4 Airbag Safety

Fatal car accidents and crashes triggered the need to improve passenger road safety. The airbag, a cushion of air in a bag, can protect the occupant from accident impact if opens in timely moment. The decision to trigger the airbag firing circuits that deploy the airbag to save the occupant's life must be made within a fraction of second to mitigate the impact of a potentially deadly force. Today in the world of embedded design, it is possible to trigger the airbag firing circuits with the aid of a microcontroller by utilizing the vehicle movement sensors, impact detection mechanisms, and complex deterministic software algorithms. Here rests the need of airbag embedded software, electronics and positional accelerometers packaged in a separate mechanical housing attached to the rigid vehicle chassis. Further interfaces to the airbag module are seatbelt position sensing circuits, sophisticated airbag firing mechanisms and a backup power supply. The airbag system is safety-critical equipment, and in the realm of automotive electronics it enjoys the highest level of fault-tolerant system with least possible dependency on other vehicle resources due to nature of its intended safety task.

1.5 Antilock Brake, Traction and Stability

If you live in a place where snow is second nature, then you are the right candidate for a vehicle with an anti-lock brake mechanism. Antilock brake systems can mitigate undesirable vehicle slip movements during icy and slippery conditions that pervade this season. This slippage occurs when one drives on slippery road conditions and applies brakes that tend to lock one or more wheels due to the low traction. The loss of even traction—on top of a slippery road—causes the vehicle to spin out of control. In order to control the wheel skidding motion, the skidding-wheel brake must be released swiftly and automatically to prevent the vehicle from going out of control. Indeed, that is the function of a typical antilock brake system. The antilock system performs tasks to avoid wheel locking conditions while the brakes are applied, and it does this automatically by measuring the angular velocity of each wheel, thereby calculating the potential slip conditions. An anti-locking brake system is composed of sensors which are able to sense the rotational speed of each wheel, perform computations based on parameters like vehicle speed and vehicle attitude and then use the solenoid controlled valves to apply and release respective brakes to counter the wheel locking conditions. The mechanism provides self-governing, single or multiple wheel brake control without any efforts from the driver as long as the brake pedal is pressed.

This has been made possible by virtue of an embedded controller developed to support a powerful closed-loop control algorithm along with the system components mentioned earlier and a motor controlled pump to generate the brake pressure hydraulics. An added feature within this domain of sensors, augmented by few more devices has been recognized as traction control where it helps to maintain and enhance the vehicle stability.

1.6 Power Assist Steering

Power steering is not new for vehicles requiring power-assist steering efforts during turns and maneuvers. It is a system based on the fluid dynamics torque characteristics utilized in the steering system to assist the driver in steering the vehicle by uniform optimum efforts. The hydraulic steering system uses the engine-driven pump to create hydraulic pressure to realize the vehicle power steering efforts.

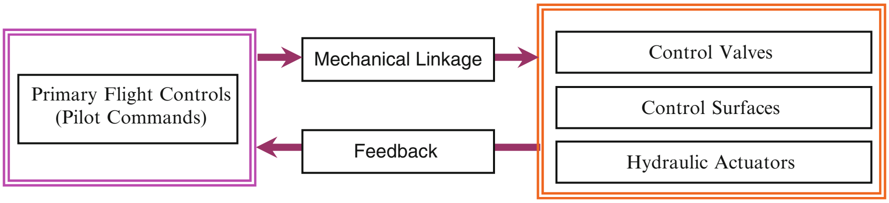

Fig. 1.1 Conventional mechanical system. Source: Boeing: Fly-By-Wire Flight Controls (B777: Public Domain Publications)

At higher vehicle speeds, the steering system adds low power assistance whereas more power assistance is added when the vehicle is moving slowly or parked. Automotive manufacturers have been working on two different topologies to develop an advanced steering system. One works on the principal of hydraulics flow metering and the other uses a high torque electric motor. Both topologies could be augmented by embedded design. Development has not stopped here. OEM's are now debating to disconnect the complete mechanical linkage from the steering column, and wish to steer the vehicle by means of electrical motors and actuators. The fully integrated system will not have any mechanical linkages but rather it will function by utilizing the electronic sensors, motors, actuators and an embedded design. A buzz- word in the automotive industry 'x-by-wire' has been used to classify such systems that utilizes electronic sensors to capture the customer commands and controls the vehicle systems with the aid of actuators and motors by incorporating embedded design.

Before we explore more on 'x-by-wire' systems, let's review the concept of 'fly-by-wire' which was introduced much earlier than 'x-by-wire' systems. Historically the word 'fly-by-wire' was first coined in Avionics design segment (**Avi**ation Electr**onics**) where it refers to the flight control surfaces like ailerons, elevators, and rudder—controlled by actuators and commanded by computers, when a pilot issues the command by moving the control yoke or rudder pedal. In essence, the pilot input goes to the sensors and not directly to the conventional mechanical linkages attached to the control surfaces.

So, what is a conventional mechanical system? A conventional mechanical system is drawn in Fig. 1.1. The mechanical linkages are attached to the cables and move control surfaces proportional to the pilot's command. The mechanical feedback allows the control surfaces to achieve the applied requested position.

1.7 Avionics Fly-By-Wire (FBW)

Unlike conventional mechanical systems, fly-by-wire systems do not use mechanical linkages that need to be attached to the pilot controls. Instead, the pilot commands go to the electronic sensors and are transmitted as a proportional electrical quantity

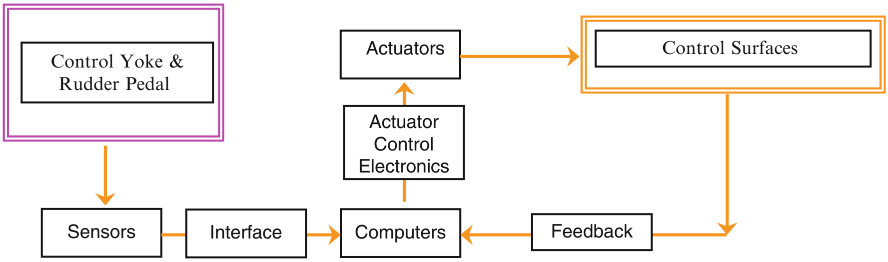

Fig. 1.2 Avionics fly-by-wire system. Source: Boeing: Fly-By-Wire Flight Controls (B777: Public Domain Publications)

to the respective electronics interface unit that digitizes the signals. The digitized signals are then fed to the primary flight computers where the appropriate processing is done. Once the processing is furnished, the computers then sends the electrical commands to actuate the actuators that move the control surfaces to the required desired position. The feedback mechanism monitors the operation of control surfaces. A simplified block is shown in Fig. 1.2

1.8 Automotive X- By-Wire

Conventionally, vehicle controls such as the brake, steering and acceleration are mechanically connected to their relevant systems. The brake pedal is attached to the brake system, the steering wheel is coupled to the steering system, and the accelerator pedal is linked to the engine throttle by means of mechanical linkages or cable. The basic design philosophy behind 'x' by wire in the minds of automotive OEMs is to remove the mechanical linkage between the driver and the systems, and use electrical controls to perform all functions. The 'x-by-wire' is the buzz word, which harnesses all three systems, namely Brake, Drive or Steer. Buzz words like 'Brake-by-wire', 'Drive-by-wire' and 'Steer-by-wire' and are often synonymously used for this purpose.

1.8.1 Brake- By-Wire

A brake-by-wire is the concept of using electrical actuators to actuate the brake pads. The concept is sketched in Fig. 1.3. The brake pedal is no longer coupled directly to the brake system, but rather it is connected to the brake pedal sensors. The sensor transforms the electrical signal to the proportional brake pedal demand and feeds it to the embedded controller. The embedded controller drives the electrical actuators to push the brake pads. A feedback is required to know the rate of deceleration that is furnished by the aid of a wheel speed sensor.

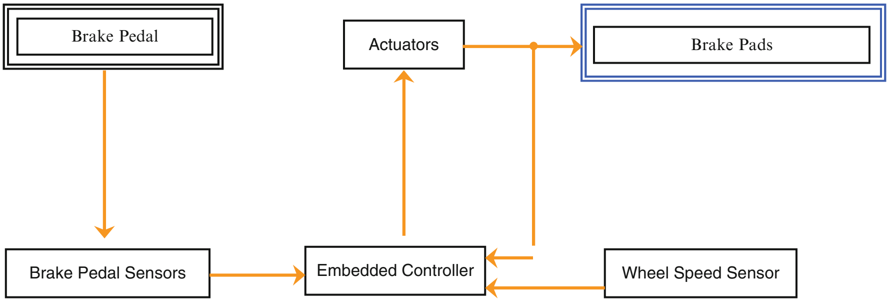

Fig. 1.3 Automotive Brake-by-wire (BBW)

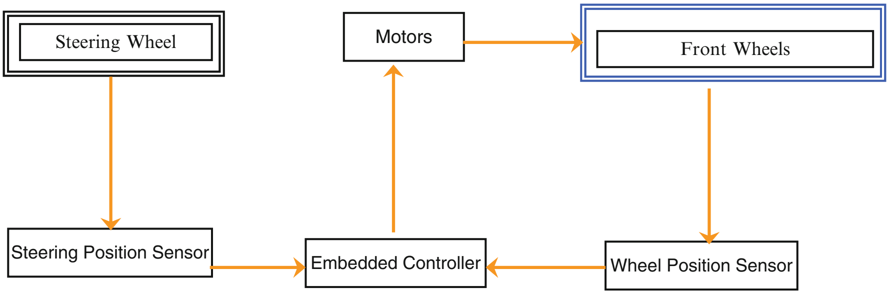

Fig. 1.4 Automotive Steer-by-wire (SBW)

1.8.2 Steer- By-Wire

The steer-by-wire (SBW) is the concept of steering the vehicle with the aid of an electric motor. The steering wheel position sensor senses the steering position, transmits electrical demand to the embedded controller. This enables the software to drive the motor to steer the wheels. The wheel position sensor transmits the feedback signal to the embedded controller to perform the closed-loop functions. Please see Fig. 1.4 for a one possible solution.

1.8.3 Drive- By-Wire

The drive-by-wire is the concept of using an electric motor to control the engine throttle and remove the mechanical linkage to the throttle. One possible solution is shown in Fig. 1.5. It is similar to preceding example. However, the control-loop is sensing multiple parameters of the throttle-position sensor, the engine torque and rpm to verify and validate the intended operational command by the customer.

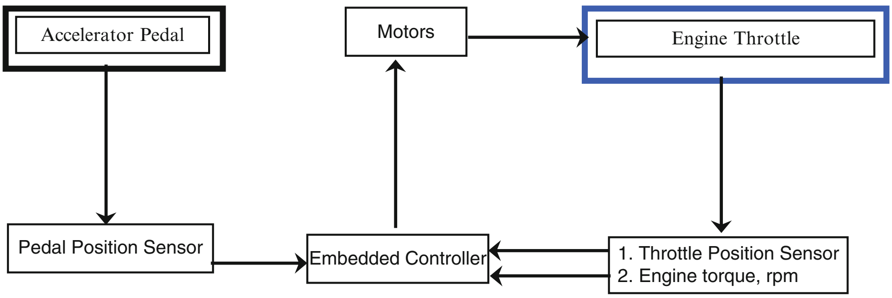

Fig. 1.5 Automotive Drive-by-wire (DBW)

The OEM's are debating whether or not to disconnect the complete mechanical linkage from the steering wheel. However, it is a safety-critical issue that requires a federal safety board review and approval. It is worth noting that the aerospace industry still kept the mechanical linkages in the fly-by-wire systems as a back-up safety should there is a complete fly-by-wire system failure.

Another intriguing application in the field of steering controls is the rejuvenation of a 4-wheel steering system. The initial concept, developed many years ago, has lately received more attention due to easy accessibility of advanced embedded design tools and software that could be used to develop better systems. The 4-wheel steering system augments the driver's efforts in a large wheel-base vehicle to reduce turning radius and maintain better stability control.

1.9 Tire Pressure Monitoring

The increased roll-over accidents involving a number of fatalities had triggered serious concerns by the federal government agencies. Low tire pressure was blamed as the major contributor to many unfortunate losses of life. The US congress passed an auto safety bill called the **T**ransportation **R**ecall **E**nhancement **A**ccountability and **D**ocumentation act (TREAD) mandating the National Highway Transportation Safety Administration (NHTSA) to develop a safety standard for the OEM's to install the tire pressure monitoring system. The vehicle manufactures were then given a time period of 3 years to complete the TPMS installations. The 3 years deadline that expired in 2006 had forced the OEMs' to implement the tire pressure monitoring system in vehicles sold across the United States of America.

The tire pressure monitoring system uses two different topologies to calculate the tire pressure and alert the driver for a low tire-pressure warning: (1) indirect method; and (2) direct method.

1. The indirect-method measures the angular velocity of each tire and computes the circumference of the tire and compares it to the pre-defined tire circumference

known previously at an accurate inflate radius. By knowing the difference of radius the embedded software calculates the tire pressure.

This method employs continuous software tasks to measure the rotational tire speed of all four tires in order to compute in real-time the tire pressure. In real world it is extremely slow and time-consuming algorithm.

2. The direct method uses the tire pressure sensors installed on each tire. The sensor uses self-contained long-life battery (5–10 years) to power the senor electronics mounted on each tire. The battery operated sensor measures the tire pressure and transmits that information by modulating the data over radio frequency carrier (global G5 or G6 band) to the receiver. The transmitter is positioned inside the tire or mounted at the tire valve-stem. The receivers are positioned inside the vehicle electronics module. The data transmitted over the RF signal includes coded information proportional to the tire pressure with proper wheel identity. All four tire pressure sensors installed on each tire sends-out the identity information of the installed wheel location. At the receiving end, the embedded controller or the vehicle electronics module with the aid of an RF receiver decodes that information, and then processes it to alert the occupants for the low tire-pressure cautions and warnings. The cautions may include an aural sound, chime or a message displayed at a convenient location to warn about the low tire pressure.

1.10 Modules Count

So far we have captured eight major electronics and embedded design applications related directly to vehicle function. These are summarized below:

1. Engine Controller
2. Transmission Controller
3. Instrument Display
4. Heating, Ventilation and Air-conditioning Controls
5. Airbag Deployment
6. Anti-lock brake
7. Power Steering
8. Tire Pressure Monitoring

As listed, a minimum of eight microcontrollers are needed to implement all of the vehicle-related functions, assuming the fact that we intend to develop eight separate modules.

At this time you might want to ask a question: Why would we need eight microcontrollers? Why can't just one single processor like in today's personnel computer and the windows CE Operating system by Microsoft or any other real time operating system (RTOS) to implement all automotive functions?

The answer is not that simple, and requires thorough understanding of many factors like module functionalities, module installation locations, safety, redundancy, wiring lengths, operating zones, harness routing schemes, and realization of a powerful real time operating system. All of these factors must be understood in great detail before finalizing an informed decision on a single computing architecture. By the time you finished reading this book, you may be able to conclude by yourself the answers to this question and many others you might have.

Here is another quick question you might like to ask at this moment:

Is this all for embedded functions in a typical vehicle?

– The answer is a definite no.

Every vehicle has door-locks, window-glasses, window-heaters, wiper-motors, headlamps, tail lamps, turn signals, interior lights and numerous other functions. Automotive manufacturers have assigned a separate module to integrate all of these functions by incorporating electronics and embedded controllers. Sometimes all of these functions are called out as vehicle-body-functions. In the early days of automobiles, these functions used to be 'straight-wire-switch' topology where a lamp is connected to the battery through a fuse with a switch. However, in advanced automotive electronics architecture, it has been integrated as an embedded function requiring hardware and software-tasks that has to be developed and deployed.

Additional features like motorized-seats, temperature-controlled seats, motorized side-view mirrors, solenoid-operated door locks, solid-state lamps, motorized-sun-roof, and reverse parking assistance—collision avoidance, lane change warning and smart headlamps have been implemented as embedded functions. These embedded functions add value and customer convenience like when the customer turns remote keyless entry to lock or unlock the vehicle, or utilizes the dimming switch to control the interior lights or invokes the remote car starter.

1.11 Straight-Wire-Switch Topology

The rule of thumb, 'straight-wire-switch' topology was the 'old fashion' way of doing things and embedding a function is a new paradigm. Nevertheless, before you decide to jump on to the embedded-functions bandwagon, make sure that the cost and time-to-market is not an issue and that your customer is willing to pay the price so the function is not just a lamp on the vanity mirror.

A 'straight-wire-switch' topology is shown in the Fig. 1.6, where the battery power feeds the lamp in-series to a fuse with a switch. When the switch was placed

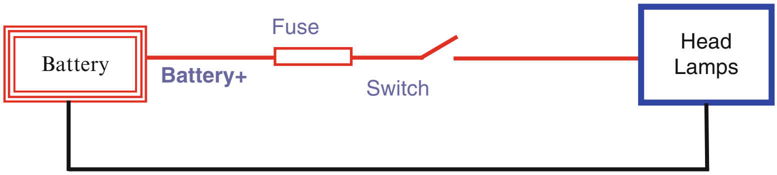

Fig. 1.6 'Straight-wire-switch' Topology

at a closed position, the lamps turned-off, and when it was switched to an open position, the lamps turned-off. The fuse protects the wiring and battery against faulty conditions. For example, an excessive current draw due to a short-to-ground condition. The fuse 'blows' if the current exceeds its rated value after a pre-defined period of time, thus opening up the circuit to avoid catastrophic damage to the active components, which may cause fire or turn into a safety hazard.

In the early day of automobiles, almost all electrical contents in a typical vehicle like window-glass-motors, defrost heater, door-lock-solenoids, turn signals, headlamps, and many others—have traditionally used 'straight-wire-switch' topology. However, this has changed over the past couple of years in the highly competitive market, where the customers are willing to pay the price and are ready to accept the changes.

United States of America, Japan, Europe, and Australia are examples where tough competitions have forced OEMs to adapt to the embedded functions.

The embedded functions have been realized and generally categorized in the following areas:

- Engine controls, Power Train and Cruise Controls
- Safety, Security and Comforts
- Driveline & Axle
- Motion, Stability and Chassis Control
- Radio, Audio, Video and Navigation
- Consumer to Automotive Interface

It is interesting to note that the automotive market in developed markets introduced advanced concepts much earlier than the developing or emerging markets. Some good examples are adaptive cruise controllers and 3D GPS navigation systems, which have successfully been introduced in Japan earlier than many other market segments.

Some of the concepts and designs have been embedded as a result of homologation requirements. For example, the European market has the homologation requirements of maintaining the headlamp-beams aim toward way-points, and must not aim unnecessarily upwards or downwards while the vehicle is travelling through an uneven terrain. The European regulation requires that the headlamps aiming must be compensated throughout the entire phase of vehicle upward or downward movements due to uneven terrain. Indeed, in order to furnish headlamp aiming tasks, a motorized headlamp assembly with vehicle pitch-attitude sensor is required to work with an embedded controller.

Another intriguing example is an auto-parking feature to demonstrate the use of image processing sensors to furnish the parallel parking capabilities. Recently an adaptive headlight feature has been introduced where the headlights turns before the vehicle turns in order to show the way-points ahead of you in advance. Just on the same principle collision avoidance, and lane departure warnings have been added in automotive domain.

The list of advanced and intriguing features goes on.

Some parts of the world where technology, life style, marketing strategy, target customers and the industrial infrastructure have not grown matured enough to handle advance automotive electronics functions, the 'straight-wire-switch' topology has still its merits.

If you happen to live in a place where automotive electronics is a 'never heard before!' phrase with a shrug, then you have an entire new market segment waiting to take up the challenge. If you wish to accept the challenge and have desire to introduce embedded functions to attract a customer's attention then you might want to research how to generate value added results by selecting the functions that could generate real tangible results.

Historically, automotive radio was the most visible and interactive introduction to the customer, and by its nature, added for convenience to the customer. However, the tangible results were achieved when the engine controller was introduced. The engine controller had not only facilitated the engine to work and operate efficiently, but also relieved customers from the recurring engine maintenance cost.

1.12 Embedded Function

Embedding a lamp function requires an embedded controller, embedded software, and an electronic-switch to supply battery-power to the lamp. The software code, stored inside the controller, adds intelligence to perform extended functions such as fused-lamps detection, system faults, and automatic switching of the lamp. As can be seen from Fig. 1.7, the embedded controller is controlling the headlamp directly, and the switch is only used to signal the embedded controller to turn on/off the headlamps. Recall in a 'straight-wire-switch' topology the switch was directly connected to the battery, fuse and the headlamps. However, with an embedded application, the headlamp turn on/off- switch is no longer connected to the battery instead detected by the intelligence of the microcontroller. The intelligence then uses an additional electronic-switch to control the headlamp to be turned-off and turned-on.

Also note how the power to the headlamps is drawn directly from the battery. Later, we will explore why this direct power-drive to the headlamps is controlled by

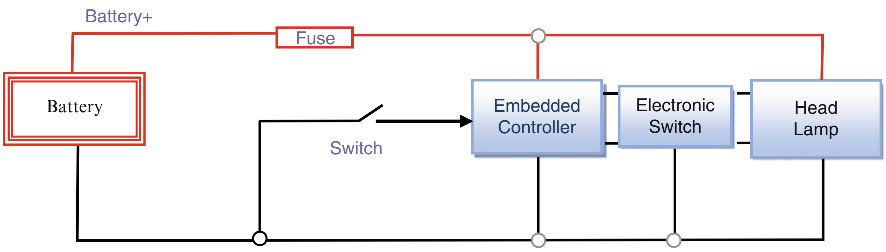

Fig. 1.7 An embedded functional block

the embedded controller as well. Indeed, embedding a function does add complexity, but with more benefits. The benefits in the longer run are helpful and intriguing.

A brief overview of embedded functions verses its overheads are tabulated in Table 1.1. As summarized in the table the activities of product development cycle have many overheads. There are tasks and challenges for the development team to define hardware & software requirements, system interfaces, write code, and struggle through hardware and software integration process to prove that the product is working as intended. While the electronics team is performing these tasks, the mechanical design team has to enclose the electronics in a proper fit, form and finish.

When the design meets the needs and wants of the intended function, and a prototype module is available, then it is tested at various test set-ups and finally connected to the vehicle interfaces by using wiring and connectors. Testing, verification and validations are conducted at the basic module level and then carried up to the vehicle level. At the vehicle level, weight and space is also a significant factor. The wiring and connectors are mandatory requirements to realize a module's physical installation so that it could be connected to the vehicle interfaces and other harnesses.

However, nothing is free in the design and development world, so cost and time are additional factors one has to consider before switching to embedded paradigm

An interesting application of embedded lamp function is the auto-lamp function, where the headlamps can be turned-on automatically when the ambient light condition falls below a certain lighting threshold. Additional benefits of embedding a function includes, but is not limited to, system fault-detection, fused-lamp detection, self-test and automatic lamp shut-off. Please see the Table 1.1 for an overview of head lamp embedded features verses overheads.

If it is desired to use High Intensity Discharge (HID) type head lamps, then the embedded controller can be fitted with HID drivers, and when it is desired to use an array of light emitting diodes (LED) then it will have to be driven by LED drive circuitry. An interesting feature of lamps or LED's is its light dimming control. The light dimming control of lamps, or LED's, requires modulation to the power driving pulses. Hence, in any application of lighting, if it is desired to control the light dimming control then the embedded controller should be fitted with **P**ulse **W**idth **M**odulated (PWM) drive circuitry to control the lamp intensity. The pulse width

Table 1.1 Head Lamp embedded features verses the overheads

Head lamp embedded features	Overheads	
• Fault detection	– Design	– Development
• Automatic lamp control	– Hardware	– Software
• Automatic shut-off	– Weight	– Space
• Fused-lamp detection.	– Wiring	– Connector
• Software Function/Upgrade	– Test	– Validate
• Self-test		

modulation is manageable with the aid of an embedded controller and a piece of software code. The LED headlamps and tail lamps have already been introduced in the automotive industry, and are increasingly showing strong market demand for variety of automotive applications. A strong presence of cockpit-related applications are indicating that the vehicle instruments and lighting systems will eventually be using high-power LED's even for exterior lights in a typical vehicle.

1.13 A Conventional Radio

The passion of embedding automotive functions had grown so strong that today sound features of a car-audio like volume, base, fader, treble and balance are no longer simple analog-type applications—rather all the sound functions of a decent car-radio are carried out by the digital signal processors (DSP) with the assistance of an embedded controller.

In order to present a comparison of a conventional radio verses the embedded radio, a block diagram of a conventional radio is shown in Fig. 1.7. As can be seen in the block diagram, the RF (Radio Frequency) tuner is connected to the antenna in order to capture the radio frequency signal energy. The tuning knob connected to the tuner is used to tune the incoming radio signal (FM 98.5 or 105.1 … radio station for example). Once the station is tuned to the desired channel, the carrier frequency is demodulated, and the signal is fed to the intermediate frequency (IF) amplifier. The signal is then fed to the audio power amplifier to drive the speakers. The switches and knobs control the audio sound features by adjusting the gains and tuning frequencies using variable active or passive components, which are basically connected to the tuning circuits and amplifiers. The dials and pointers are the status information for the user to know the station tuned, volume level and band.

Note the absence of microcontroller, Digital Signal Processor (DSP) and how the sound features are controlled by switches and knobs—connected directly to the power amplifier.

1.14 An Embedded Radio

As stated earlier, the embedded-radio sound functions are carried out by software with the aid of a Digital Signal Processor (DSP) and a microcontroller. Both, working as a team with other peripherals, furnish all the functions associated with a radio drawn in Fig. 1.8. The software plays a huge role in an embedded radio. Software tasks are shared by the DSP and the microcontroller. The signal-processing, math-intensive calculation tasks and powerful stored algorithms are executed by the DSP; however, the control over all other peripherals including user interaction is managed by the microcontroller. The embedded controller on one hand interacts with the user, and on the other hand communicates with the DSP, programmable radio frequency (RF) tuner, audio power amplifier and other peripherals.

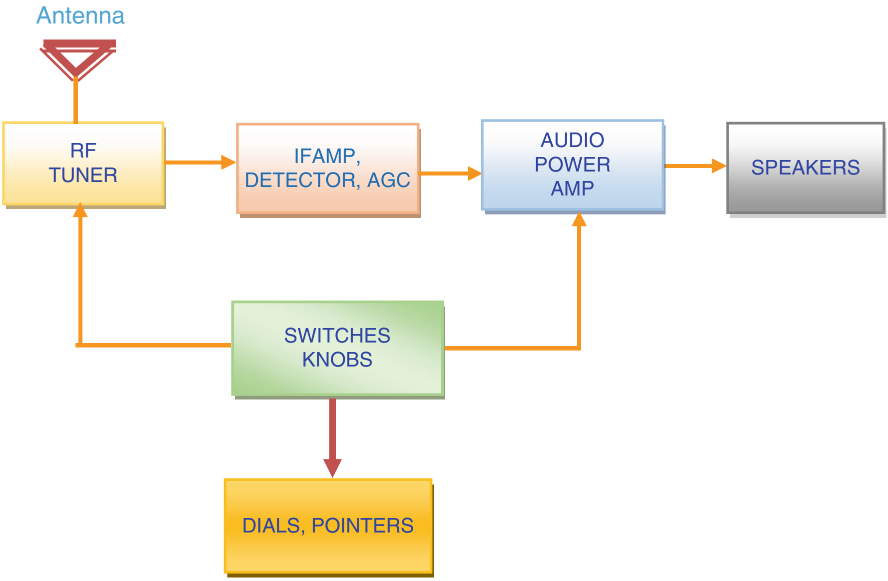

Fig. 1.8 A conventional radio

It is interesting to note that the user controls like power On-Off switch, station tuning and volume controls are inputs to the microcontroller, and are no longer directly connected to the tuner or the amplifier, which is different than what has been done in the conventional radio. The radio station-tuning is achieved by sending digital commands to the programmable tuners. The signal filtering, audio and radio processing is primarily performed by the digital signal processor

The customer requests, in the form of key-presses and knob-adjustments, go directly to the microcontroller as depicted in Fig. 1.8.

The output of the DSP feeds the audio amplifier either through a pre-amplifier or directly to the power amplifier, which drives the speakers. Now, the question comes to your mind:

How do I see which station I tuned to? How do I control other settings like volume, base, treble, balance, fader and more?

The answer to this and many other user interactions and requirements are resolved by adding a switch-matrix and a display. The switch matrix allows the user-commands to be read by the microcontroller. The display shows the status of adjustments, thereby enabling the customer to dynamically interact with the radio functions. The block diagram of an embedded radio is shown in Figs. 1.8 and 1.9.

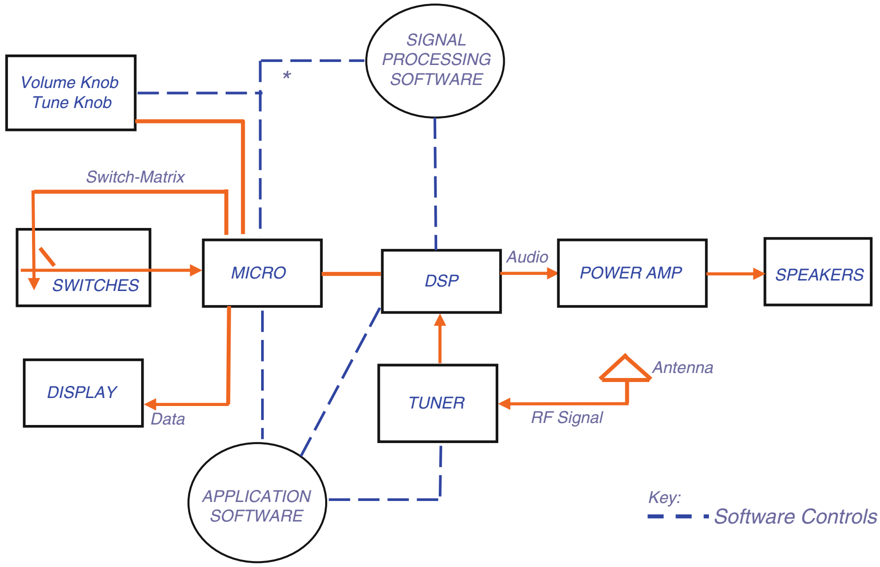

Fig. 1.9 An embedded approach to audio and radio functions

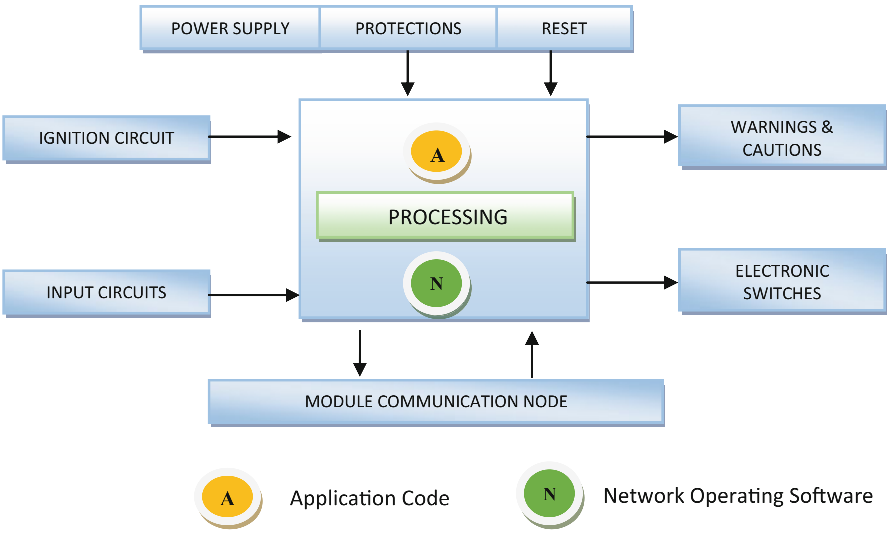

Fig. 1.10 General Block Diagram of a module