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Faculty of Technology
Department of Electronics

Course Handout

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Program: Electronic

Specialization: Embedded Systems Electronics

Embedded System for Automotive

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Table of contents

Chapter II: Sensors for Embedded

Chapter III : Actuators for embedded systems

Chapter IV : Vehicle system architecture

Chapter V : Embedded Systems in Automobile

Chapter IV : Typical architecture of a vehicle model manufactured in Algeria

Figures List

Tables List

Preface

This course material for the "Embedded Systems for Automobiles (ESA)" module is intended for first-year Master's students in embedded systems electronics within the official curriculum, as well as other students from different specializations in the Departments of the Faculty of Technology at the University of Chlef (UHBC).

In fact, the objective of this course material is to provide students with the necessary foundations to know how to develop and design embedded electronics applications for automobiles, which is a discipline in its own right aimed at optimally controlling a vehicle's movement and safety.

This material covers the basic elements of embedded technology in the automotive sector. Numerous examples of real and prospective figures illustrating the principles studied in these courses are presented.

Upon completion of this module, the student will be able to:

- ✓ *Understand the architecture and operation of a combustion engine (Automobile) and grasp the concept of an embedded system.*
- ✓ *Grasp the main characteristics of an embedded system, their stakes, and the challenges of embedded systems.*
- ✓ *Understand the role of sensors for embedded systems, know their operating principles, and acquire interfacing methods.*
- ✓ *Identify the actuators in an embedded system and the different types of actuators.*
- ✓ *Present the concepts of electronic and software architecture, understand the role of electronic control units (ECUs), and identify the main subsystems (Sensor/Actuator Networks).*
- ✓ *Understand the electronic regulation of dynamic behavior (ESP) and the different methods for measuring rotational speed (encoder, Doppler effect).*
- ✓ *Analyze the technical and organizational structure of vehicles assembled or manufactured locally in Algeria by analyzing their key components.*

General Introduction

Embedded systems are at the heart of technological innovation today, especially in the automotive field, where they play an essential role in improving vehicle performance, safety, and comfort. This course material, intended for Master 1 students in embedded systems electronics (and other related specializations), aims to provide a solid foundation on the fundamental concepts of embedded systems applied to automobiles.

The modern automotive industry relies increasingly on intelligent electronic systems, integrating sensors, actuators, electronic control units, and communication networks. These systems enable:

- *Engine control (injection, ignition, energy management).*
- *Active safety (ABS, ESP, airbags).*
- *Comfort and connectivity (infotainment, navigation).*
- *The emergence of autonomous and electric vehicles.*

In Algeria, with the development of the local automotive industry, mastering these technologies has become a strategic issue for engineers, technicians, and various academic researchers.

This teaching material is organized into six chapters, preceded by a general introduction:

- *The first chapter introduces embedded systems, their role, and their key components.*
- *The second chapter presents the different sensors for embedded systems in the automotive sector, their roles, and methods for detecting and transforming information for the electronic block.*
- *The third chapter presents the different actuators for embedded systems in automobiles, their roles, and their technological evolution.*
- *The fourth chapter addresses the vehicle system architecture through the different automotive subsystems.*
- *The fifth chapter deals with embedded systems in automobiles: types, components, and selection criteria.*
- *The last chapter is dedicated to the typical architecture of a vehicle model manufactured in Algeria, their design adapted to the Algerian market, and their integration into the national industrial ecosystem.*

Chapter I

Introduction to Embedded Systems

- ✓ *Architecture and operation of a thermal engine (Automotive)*
- ✓ *Understanding the concept of an embedded system*
- ✓ *Understanding the areas of application*
- ✓ *Understanding the main characteristics of an embedded system.*
- ✓ *Architecture of embedded systems*
- ✓ *Issues and challenges of embedded systems*

1. Introduction

The modern automobile has undergone a radical transformation, evolving from a purely mechanical device into a high-tech ecosystem where embedded systems play a central role. These systems, composed of electronic hardware, specialized software, and communication networks, are now at the heart of the vehicle's essential functions, whether it's for safety, performance, comfort, or connectivity.

Today, a car can integrate up to several hundred electronic control units (ECUs), interconnected via embedded networks (CAN, LIN, etc.), which control functions as varied as engine management, advanced driver-assistance systems (ADAS), infotainment, or autonomous driving. These systems must meet strict constraints in terms of real-time performance, reliability, and safety, while also evolving toward increasingly integrated and intelligent architectures.

This chapter is divided into two parts:

The first part is dedicated to general information about the automotive engine (four-stroke internal combustion engine) as the heart of the vehicle. We will examine in detail the operating principles of these internal combustion engines, their mechanical architectures, and their key components. Special attention will be given to the thermodynamic cycles for the combustion process that enable this energy conversion.

The second part offers an introduction to embedded systems and their increasing integration to perfect thermal power trains, creating a technological synergy where mechanics and electronics mutually enrich each other. This joint approach is essential for understanding modern vehicles and anticipating future developments in the automotive industry.

2. General Overview of the Heat Engine (Four-Stroke motor)

A motor is a device that converts a supplied energy source into mechanical work. It is called a heat engine if the energy source is a fuel. Through combustion, the fuel is converted into caloric or thermal energy.

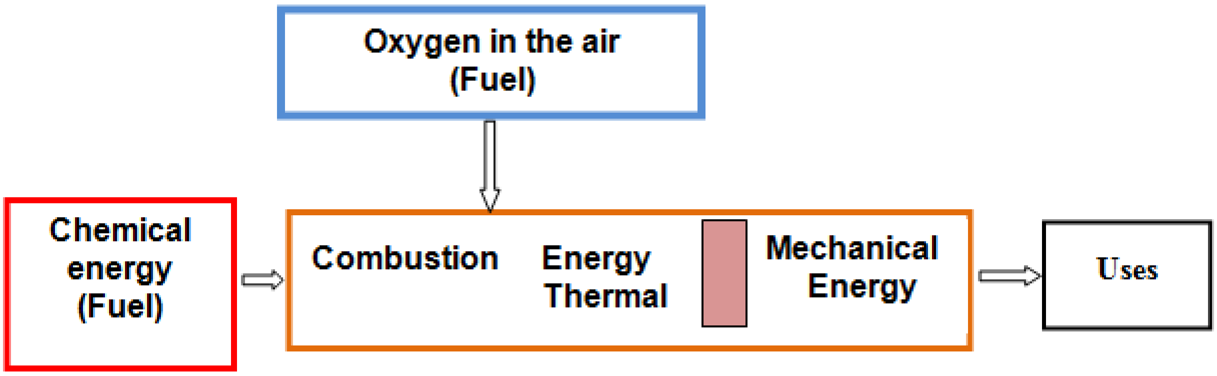


Figure I.1.Energy transformation chain of the heat engine

All heat engines use the thermodynamic transformations of a gas mass to convert the chemical energy contained in the fuel into mechanical energy directly usable on the engine shaft.

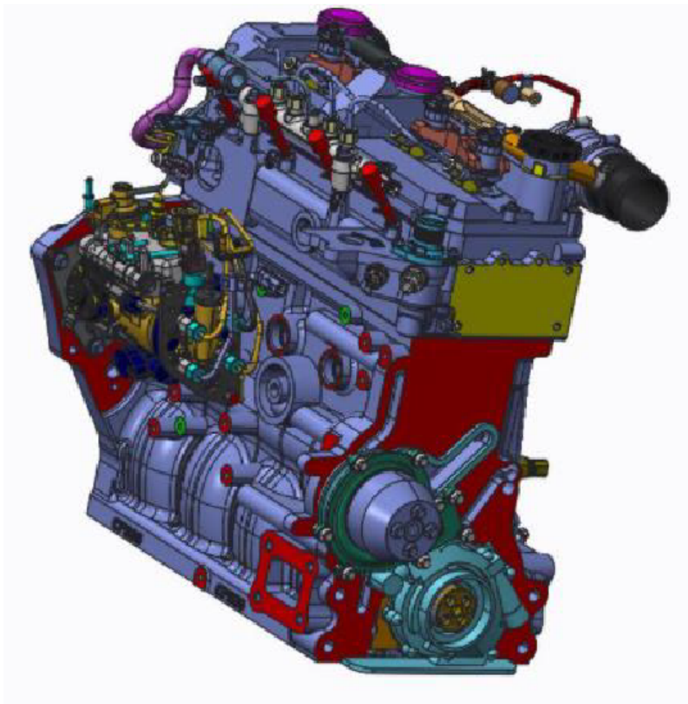


Figure I.2.Four-stroke heat engine

2.1. Functional Analysis

The operation of the heat engine is ensured by the association of four main functional groups:

- The chamber system which ensures the isolation of the gas mass.
- The connecting rod-crank system to ensure the transformation of the piston's alternating rectilinear motion into a rotational motion.

- The timing system which controls the opening and closing of the valves at the appropriate times.
- Internal combustion engine fuels; generally, the fuels used in automobiles are: gasoline, LPG, and diesel.

The four-stroke engine includes a moving assembly made up of the piston, the connecting rod, and the crankshaft. This assembly is surrounded by the engine block, which includes the cylinders, the cylinder head, and the crankcase. The piston slides in the cylinder, and the connecting rod transmits this movement to the crankshaft. The connecting rod-crankshaft assembly transforms the alternating motion of the piston into a circular motion.

The introduction of fresh gases is done by an intake valve (S), and the evacuation of burnt gases is done by an exhaust valve (S'). The opening of these valves is accomplished by the camshaft. The fuel-air mixture, or carbureted mixture, is created by the carburetion or injection system. The combustion of the mixture in the explosion chamber is caused by an electrical spark that jumps between the electrodes of the spark plug.

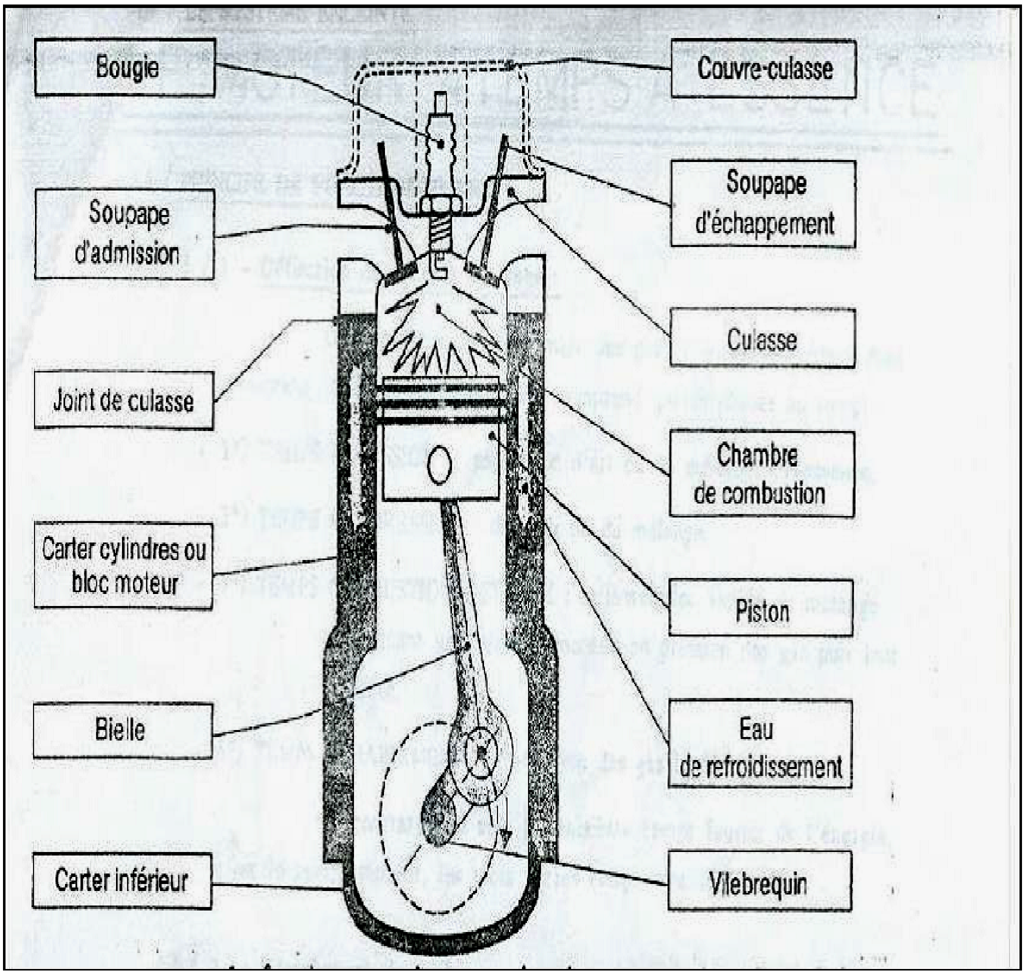


Figure I.3.Functional description of a heat engine cylinder

2.2. Operating Principle

The complete cycle consists of 4 piston strokes, which equals 2 crankshaft revolutions.

2.2.1. First Stroke: Intake

The intake valve is open, and the exhaust valve is closed. The piston moves down (to the BDC - Bottom Dead Center), drawing in the mixture (or air in the case of a Diesel engine) directly from the intake manifold.

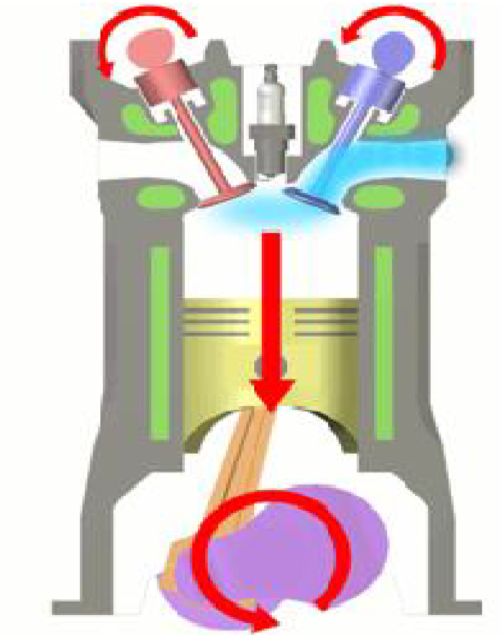


Figure I.4. Intake Phase

2.2.2. Second Stroke: Compression

Both valves are closed; the piston moves up, compressing the gases. This causes a temperature increase that brings the air or mixture to a level that is favorable for the explosion.

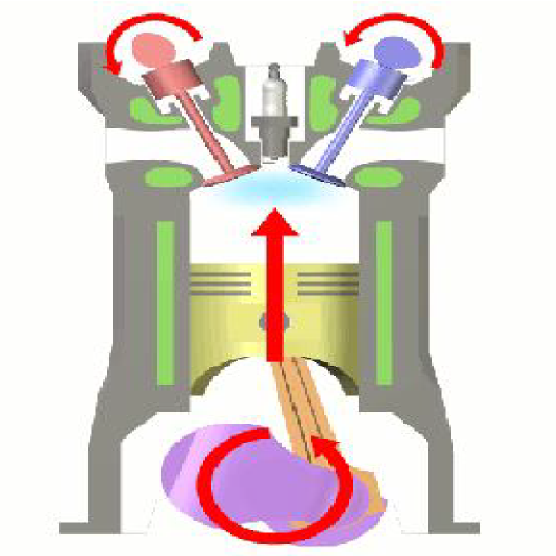


Figure I.5. Compression Phase

2.2.3. Third Stroke: Combustion and Expansion

Just before the TDC (Top Dead Center), an electrical spark triggers the combustion process. The increase in pressure exerted on the piston generates a force on the connecting rod, and thus, a driving torque on the crankshaft. The piston moves back down to Bottom Dead Center (BDC).

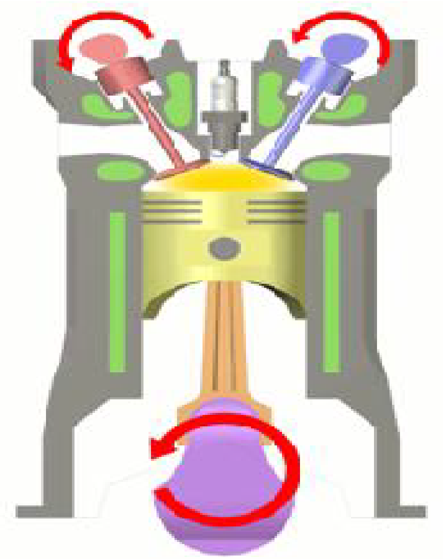


Figure I.6. Combustion and Expansion Phase

2.2.4. Fourth Stroke: Exhaust

The piston reaches the end of the expansion stroke at the bottom of the cylinder (BDC - Bottom Dead Center), then it moves back up.

The exhaust valve is open, and the burnt gases can escape through the exhaust manifold.

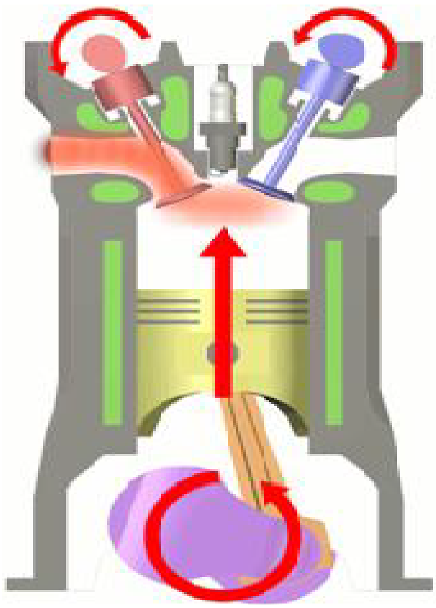


Figure I.7. Exhaust Phase

3. **Table I.1.** Summary of four-stroke engine operation

Stroke Number	Phase Name	Displacement		Position of the Valves O : Open C : Closed		Observations
		Piston	**Crankshaft**	**Intake**	**Exhaust**	
1st Stroke	Intake	↓	A half-turn	***O***	***C***	As the piston moves down, it creates a drop in pressure, which facilitates the intake of gases.
2nd Stroke	Compression	↑	Second half-turn	***C***	***C***	The piston compresses the gases until they only occupy the combustion chamber (pressure + heat).
3rd Stroke	Combustion-expansion	↓	Third half-turn	***C***	***C***	The spark from a spark plug (or the injection of compressed diesel) ignites the mixture. The heat released expands the gas, which forcefully pushes the piston downward.
4th Stroke	Exhaust	↑	Fourth half-turn	***C***	***O***	As the piston moves back up, it expels the burnt gases. The engine is then ready to perform the first stroke again.

2.3. Ignition System

2.3.1. The Conventional Ignition System

The ignition system of a car, which is essential for the operation of a gasoline engine, aims to create a spark inside the cylinders to ignite the air-fuel mixture. It converts the low voltage from the battery into the high voltage needed to generate this spark, thus enabling combustion and the engine's operation.

The ignition system works in synchronization with the engine to ensure the spark occurs at the right time, allowing for efficient combustion and proper engine function.

The main components and their roles:

- **Battery:** Supplies the initial energy source.
- **Ignition Coil**: Transforms the low voltage from the battery into high voltage.
- **Spark Plugs**: Generate the spark in the cylinders to ignite the air-fuel mixture.
- **Distributor (on some systems):** Distributes the spark to the different spark plugs in the correct order.
- **Ignition Module (Igniter):** Manages the precise timing of the ignition.

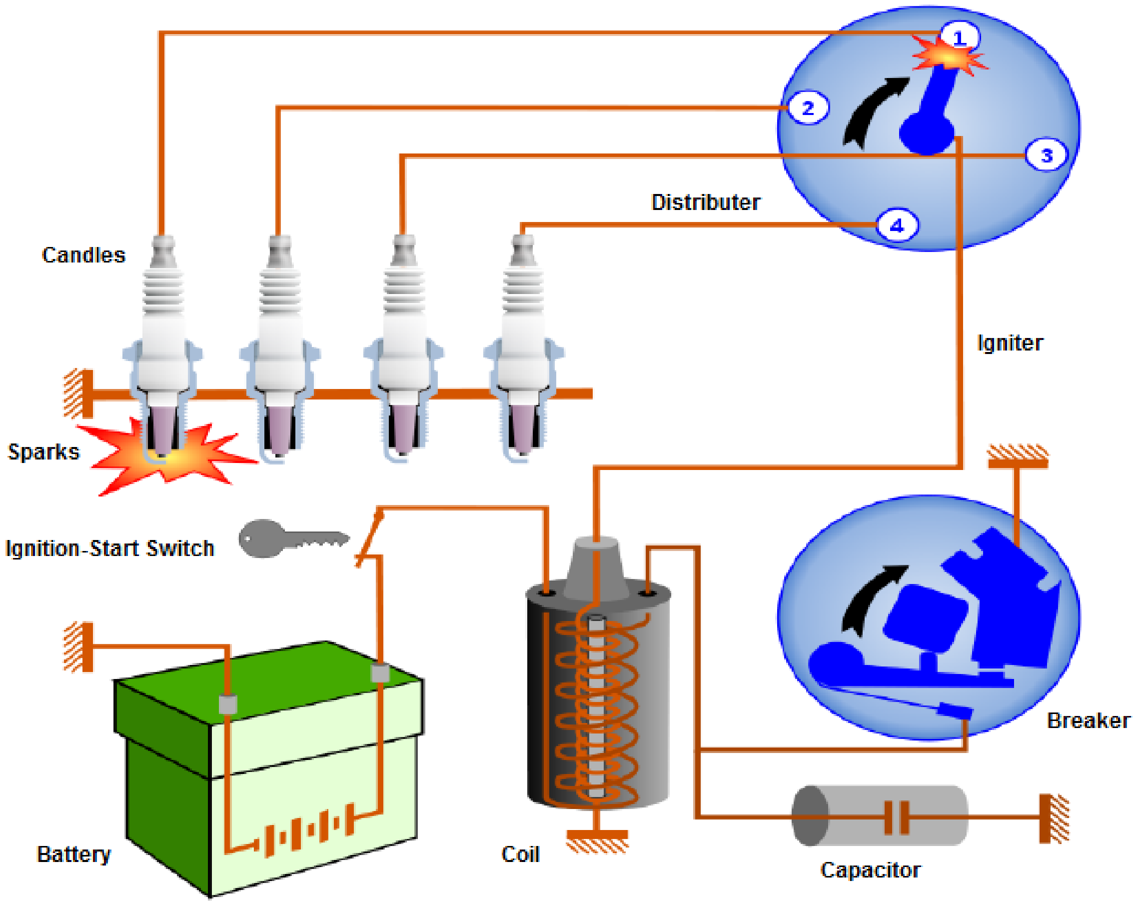


Figure I.8. Example of simple ignition circuit diagram

2.3.2. Integrated Ignition System (Electronic Ignition)

This system replaces the contact breakers with an ignition module (a static electronic device). The ignition is triggered based on information gathered by sensors: one for position and another for engine speed.

The information received is transmitted to an electronic control unit (ECU). After processing, the ECU sends commands to the ignition coil to generate high voltage. This high voltage is then sent to the spark plugs via a mechanical distributor.

An integrated car ignition system, also known as Fully Electronic Ignition (FEI), is an electronic system that controls the production and distribution of the spark needed to ignite the air-fuel mixture in the engine. It replaces older mechanical ignition systems, offering greater precision, reliability, and efficiency.

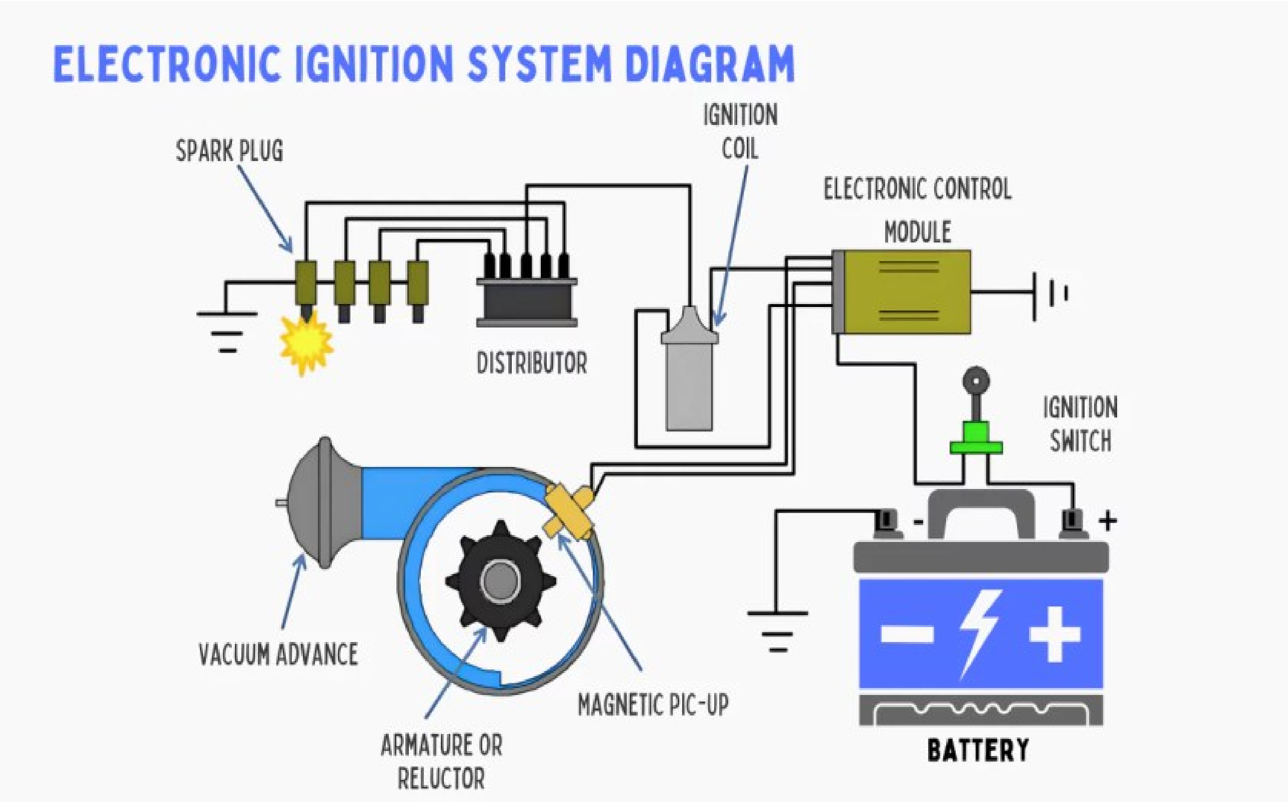


Figure I.9.Example of an electronic ignition circuit diagram

The electronic ignition system, like other ignition systems, is relatively simple and easy to understand. When the engine starts with the ignition on, power is supplied by the battery, connecting the negative terminal to the ground and the positive terminal to the ignition switch. This energy is directed to the ignition coil, which is made up of primary and secondary windings.

An iron core placed between the windings generates a magnetic field. The rotation of the armature, connected to the electronic module, creates this magnetic field, which in turn produces a voltage signal. This signal intensifies until it becomes powerful.

The voltage is then sent to the distributor, which houses a rotor and distribution points timed according to the ignition advance.

When the rotor aligns with a distribution point, the voltage passes through the rotor's air gap to the distribution point, and then is transmitted to the adjacent spark plug terminal via the high-voltage cable.

3. Definition and Basic Concepts

- The term "system" refers to all the elements that make up the embedded system; these systems are often composed of subsystems due to their complexity.
- The term "embedded" represents the mobility and autonomy of the system, which interacts directly with its environment to perform specific tasks and fulfill its purpose.
- An embedded system is a set of computing and electronic elements that interact with each other in an autonomous and complementary way. These systems are designed to specifically meet the needs of their respective environment.
- Unlike traditional systems, embedded systems are designed to perform very specific tasks. Some must meet real-time constraints for reasons of reliability and safety, which are essential depending on the system's use.
- An embedded system brings together both the software and hardware components, which are closely linked to produce the expected results.
- An embedded system is defined as an autonomous, often real-time, and electronic and computer system specialized for a very specific task. Its resources are generally limited.
- An embedded system generally combines various technologies from the fields of mechanics, hydraulics, thermal science, electronics, and information technology.

Before going any further, it's important to make a clear distinction between embedded software and the embedded system. Even though they are complementary, they are not the same thing.

- Embedded software is: We call "software" the purely software part, or even a part of the software (there can be multiple software programs) of the embedded system of the equipment in question.
- An embedded system is: We call "system" the entire set of hardware and software embedded in a specific piece of equipment to ensure its operation.

4. Characteristics of an Embedded System

An embedded system is a specialized computer and electronic system, designed to perform a specific task within a larger device or system. It is characterized by its small size, low power consumption, and real-time operation. Additionally, it is often dedicated to a single function and is designed to be reliable and secure, with specific constraints in terms of memory, processing power, and autonomy.

An embedded system can be characterized by two dimensions: a very limited size and low energy consumption.

The main characteristics of an embedded system are:

- **Size and Integration**
  - Embedded systems are designed to be small and compact, easily integrating into the host device.
  - They are often invisible, operating in the background to perform their specific task.
- **Power Consumption**
  - Low power consumption is crucial, especially in mobile and autonomous devices.
  - Embedded systems must be designed to optimize energy use, sometimes by using standby or power-saving modes.
- **Specificity**
  - An embedded system is generally dedicated to a single function or a set of closely related functions.
  - This specialization allows for system optimization for specific tasks.
- **Reliability and Security**
  - Reliability is essential, as errors can have serious consequences, particularly in the fields of security or healthcare.
  - Embedded systems must be designed to withstand environmental conditions and hardware failures.

- **Real-Time Operation**
  - Many embedded systems operate in real-time, responding to external events within a precise timeframe.
  - Responsiveness and execution speed are important aspects of these systems.
- **Hardware Constraints**
  - Embedded systems often have to deal with constraints on memory, processing power, and bandwidth.
  - An embedded systems engineer must find a balance between these constraints and the needs of the application.
- **Cost**
  - In many applications, the mass production of embedded systems requires strict cost control.
  - The design must take these economic constraints into account.

5. Architecture of Embedded Systems

An embedded system processes input data to produce output actions. Once the data is collected and processed, the software makes a decision that the system then executes physically.

Possible Inputs:

- Sensors to gather information from the device's environment (temperature, motion, vibration, GPS, etc.).
- User inputs: Buttons touch screens.
- Wired communication buses: Ethernet, RS485, CAN, etc.
- Wireless communication: BLE, Wi-Fi, 3G/4G, LoRa, etc.

Possible Outputs:

- Actuators: Motors, solenoid valves, coils, magnets.
- Communication: An output that transmits information to another system for processing.
- HMI (Human-Machine Interface): Displaying information on a screen or with LEDs.

An embedded system is made up of many elements that we will present to you right here:

- **Sensor**: For example, a sensor that receives information.

- **Analog-to-Digital (A/D) and Digital-to-Analog (D/A) Conversion**: Converters to transform a physical signal (e.g., electrical) into a digital signal (numbers) and vice versa.
- **CPU (Central Processing Unit)**: The central computing unit (processor or microprocessor).
- **Memory**: The storage unit.
- **FPGA (Field-Programmable Gate Array)**: A reprogrammable integrated circuit.
- **ASIC (Application Specific Integrated Circuit)**: In contrast, this is a circuit specific to a function and is not modifiable.
- **Actuator**: The component that performs the function, for example, a motor that starts up.
- **Microcontroller**: An integrated circuit with multiple components, such as a CPU, memory, and peripherals.

Here is a diagram to help you visualize what it might look like:

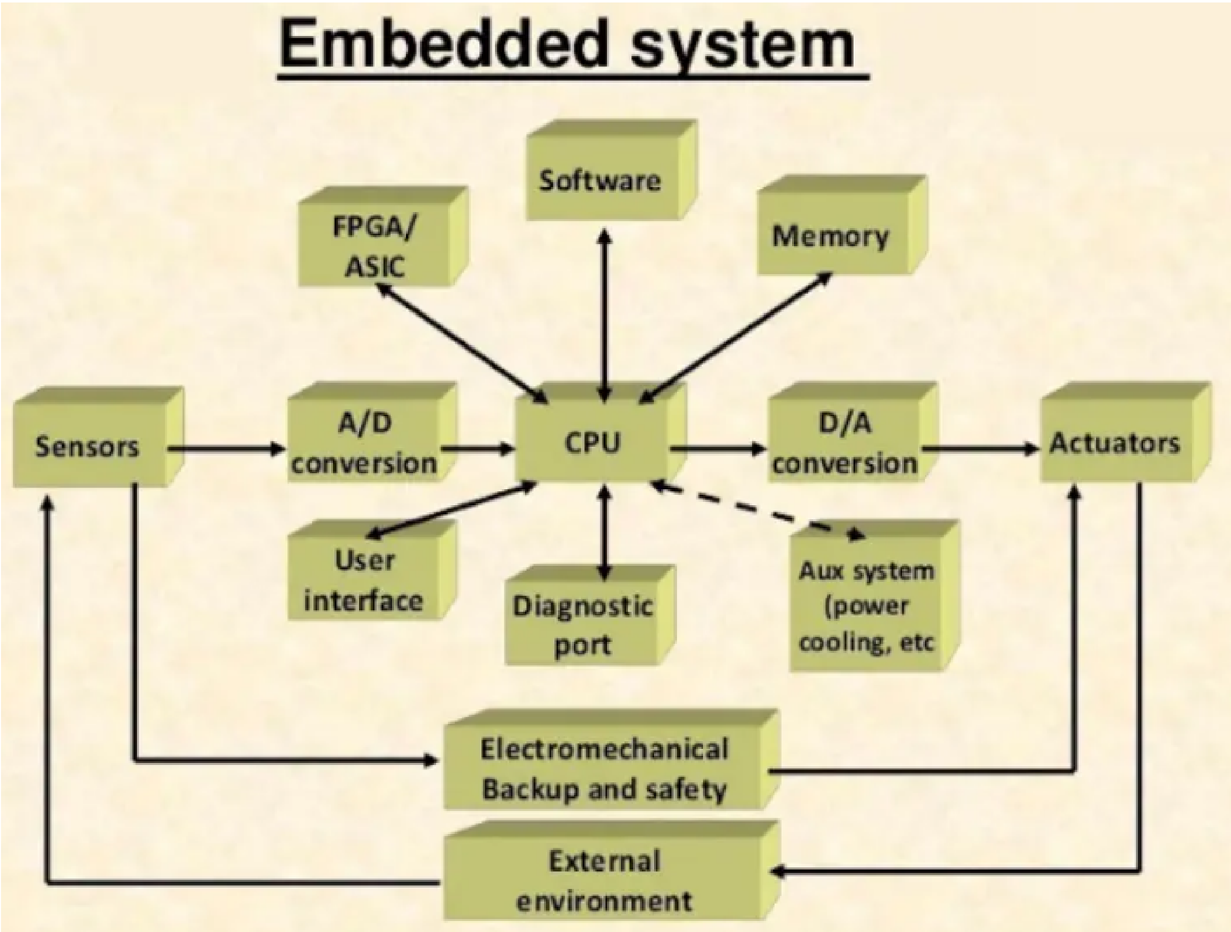


Figure I.10. Typical embedded system architecture

6. The Limitations and Constraints of an Embedded System

Embedded systems perform predefined tasks and must adhere to a strict set of specifications. As a result, they are subject to various physical, operational, software, and hardware constraints. In the automotive sector, embedded systems face significant challenges, especially with the rise of connected, autonomous, and electric vehicles.

6.1. Memory Space

Memory space can be very limited, often only a few GB at most. This constraint is driven by the increased manufacturing cost and energy consumption of these systems. Therefore, it's essential to precisely calculate the device's memory needs to create a system that is perfectly suited for its use case. Even with component miniaturization, memory remains a critical constraint that must be managed to meet system requirements.

6.2. Battery Life

Battery life is a major issue for embedded systems. Many are autonomous and must operate on batteries or other power cells. Power consumption must be minimized and calculated as precisely as possible to reduce costs, battery size, and the need for frequent charging or battery replacement. While a standby mode can help, optimizing power usage remains a constant priority.

6.3. Processing Power

Processing power must be precise and sufficient for the embedded system to perform its intended task. However, it shouldn't be overly powerful, as this can lead to issues with excessive power consumption or a form factor that is too large.

6.4. Reliability and Safety

Embedded systems are used in fields where even a minor error can have severe consequences, such as in medical, military, and aerospace applications. These systems must be flawlessly reliable to guarantee user safety. In some cases, the primary function of the embedded system itself is to ensure the safety of users to prevent any errors.

6.5. Real-Time Operation

The concept of real-time is crucial. A system is considered "real-time" when information remains relevant after it has been acquired and processed. More specifically, for information that arrives periodically, the acquisition and processing times must be shorter than the information's refresh period. The goal is to guarantee a maximum execution time, not just an average one.

For this to happen, the real-time kernel or system must be:

- Deterministic: The same inputs always produce the same outputs with the same execution times.
- Preemptive: The highest-priority task that is ready to run must always have immediate access to the processor.

6.6. Cost and Industrial Optimization

Cost constraints and industrial optimization are major challenges for car manufacturers and their suppliers. Their primary objective is to reduce expenses while maintaining the quality, performance, and reliability of embedded systems. In the automotive industry, embedded systems account for 30% to 40% of a vehicle's total cost.

Examples:

- Tesla (HW3): Uses 3 main computers instead of 70.
- Volkswagen: Achieved a 40% reduction in wiring.
- Bosch: Uses a modular (reusable) ECU, leading to a 30% gain in development time.
- Toyota: Employs a common platform (TNGA) for several models, resulting in a 20% gain in costs.

7. Applications of Embedded Systems in the Automotive Industry

Embedded systems are everywhere in modern vehicles, handling functions that range from safety to comfort, as well as connectivity and autonomy. All of these systems must meet strict demands for security, cost, and reliability.

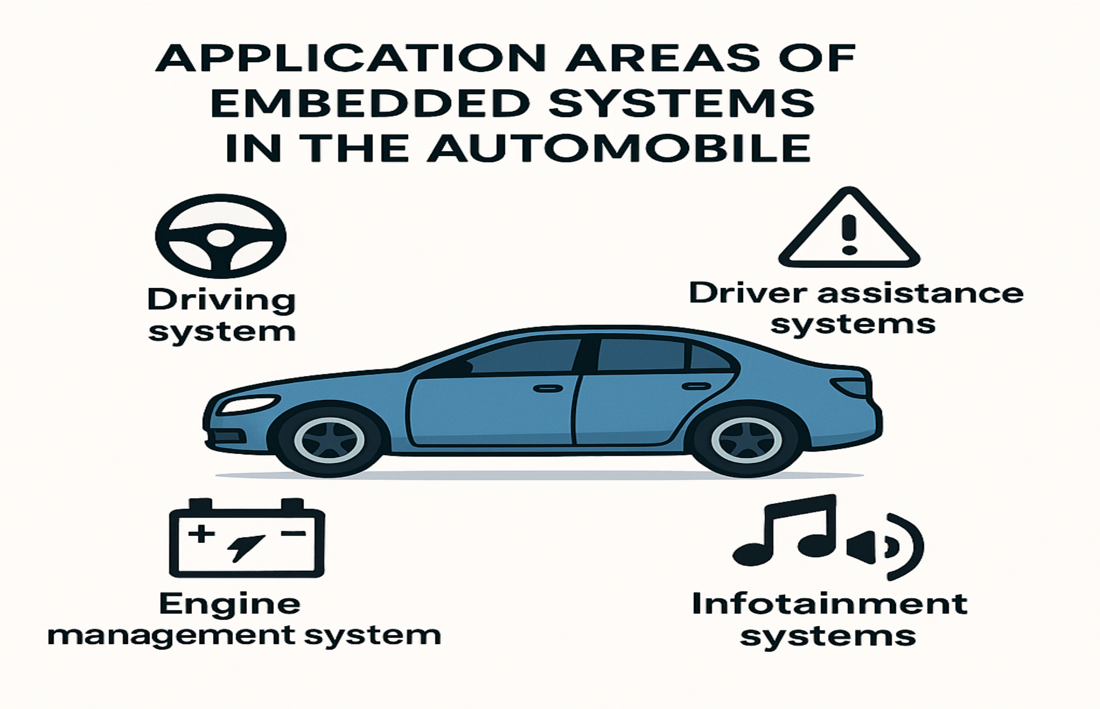


Figure I.11. Application Areas of Embedded Systems in the Automobile

The primary application areas of embedded systems in automobiles:

7.1. Active and Passive Safety

- **Active Safety (Accident Prevention)**
  - ✓ **Anti-lock Braking System (ABS):** Electronic control of braking to prevent wheel lock-up.
  - ✓ **Electronic Stability Program (ESP):** Corrects the vehicle's trajectory in the event of a loss of traction.
  - ✓ **Automatic Emergency Braking (AEB):** Automatically applies the brakes in the case of an imminent collision.
- **Passive Safety (Occupant Protection)**
  - ✓ **Airbags:** Deployment in milliseconds via crash sensors.
  - ✓ **Pre-tensioned Seat Belts:** Electronically activated before an impact.

7.2. Advanced Driver-Assistance Systems (ADAS)

These are driver-assistance systems that are precursors to autonomous driving:

- ✓ **Adaptive Cruise Control (ACC):** Regulates speed and distance from the vehicle ahead.
- ✓ **Lane Keeping Assist (LKA):** Helps keep the vehicle in its lane.

- ✓ **Traffic Sign Recognition (TSR):** Recognizes road signs using cameras and AI.
- ✓ **Parking Assist:** Autonomous parking assistance using ultrasonic sensors and cameras.

7.3. <u>Diagnostics and Maintenance</u>

- ✓ **On-Board Diagnostics (OBD-II):** Monitors for engine faults.
- ✓ **Predictive Maintenance:** Analyzes data to anticipate failures.
- ✓ **Over-The-Air (OTA) Updates:** Software updates that can be installed without a visit to a workshop.

<u>Exemple</u> (RENAULT)

The 4Control system, developed by Renault, allows the steering angle of the rear wheels to be adjusted based on the vehicle's speed.

- **Below 60 km/h (37 mph)**, the rear wheels turn in the opposite direction to the front wheels for greater agility. This reduced turning radius makes maneuvering easier. Less steering input is needed, which improves handling on winding roads and increases driving comfort.
- **Above 60 km/h**, the rear wheels turn in the same direction as the front wheels. This helps the rear of the car follow the exact trajectory of the front, providing optimized stability and a feeling of enhanced confidence.

Figure I.12. The 4Control System Developed by Renault

Coupled with the electronic ESP systems, this four-wheel steering chassis provides enhanced safety during difficult braking conditions and, most importantly, during avoidance maneuvers. The implementation of this highly critical system was based on redundancy and monitoring of the calculations performed by the control unit, securing the communication between the 4Control and ESP control units, and securing the physical measurements used through specific sensors and monitoring algorithms. This chassis currently equips the Renault Laguna GT and coupé, with several thousand vehicles sold.

8. Conclusion

The revolution of embedded systems is a genuine one, not only for the field of computing, which sees ever-expanding applications, but also for our societies as a whole due to their impact on technological, economic, industrial, and environmental domains. Embedded systems are electronic components (chips) equipped with software and integrated into devices or equipment.

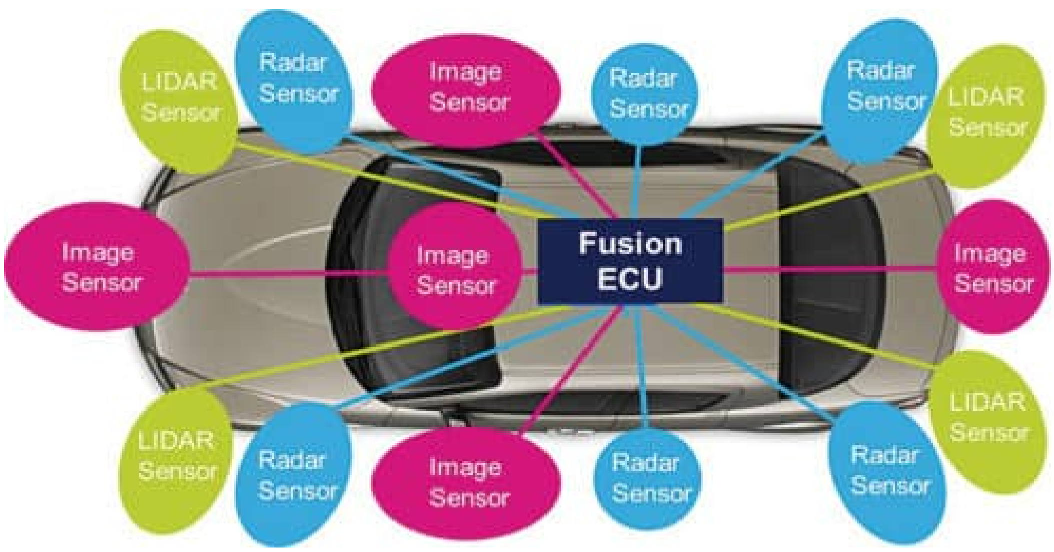
They are found in countless everyday objects (phones, household appliances, games, digital recreation, electrical equipment, etc.), where they provide new functionalities in terms of use, intelligence, and communication. They are also present in sectors where reliability, responsiveness, and robustness are crucial, such as transportation (rail, aerospace and defense, automotive, energy, etc.), healthcare, and building management.

Given the importance of embedded systems, as demonstrated in this chapter, it is essential to ensure the security of these systems, their data, and any other applications that may be present. In the next chapter, we will focus on the topic of embedded sensors.

Chapter II

Sensors for Embedded

- *Understand the role of sensors.*
- Understand their operating principles.
- Acquire interfacing methods.
- Analyze sensor data using signal processing.
- Evaluate the performance of on-board sensors.



1. introduction

Today, electronics are everywhere in a vehicle, with dozens of onboard sensors providing real-time information to multiple onboard computers.

Whether it's a seatbelt sensor, a rain sensor, automatic headlight activation, or fuel metering, all these sensors aim to improve comfort, safety, and the vehicle's impact on the environment.

Sensors are essential components in modern vehicles, playing a crucial role in safety, efficiency, and comfort. They collect real-time data on the vehicle's environment and internal state, enabling electronic systems to make informed decisions.

Figure II.1. Automotive sensors

A sensor is a detection element that converts a physical quantity into an electrical quantity that can be used by a computer.

- **What physical quantities are measured?**

Temperature, pressure, position, level, rotational speed, oxygen content, acceleration, water presence, flow rate, brightness.

- **What electrical quantities are used?**

Voltage, current, capacitance, resistance

- **What conversion principles are used?**

  Thermo-resistive, piezo-resistive, capacitive, potentio-metric, inductive, Hall effect, magneto-resistive, piezoelectric, photo-resistive, electrochemical, opt electric

2. Speed Sensor

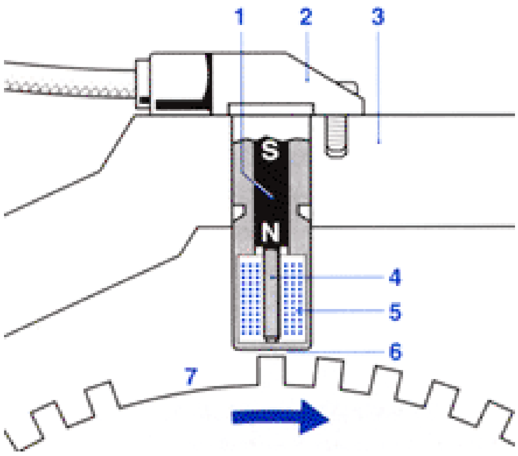
Speed (velocity) sensors are critical components used in automobiles to measure the speed of the vehicle or its components.

These sensors detect movements and position changes using various technologies and then transmit this information to other vehicle systems.

To capture movements (rotational speeds, crankshaft rotations, etc.) and positions (crankshaft position), sensors that operate on the induction principle (also called inductive sensors) are used.

Figure II.2. Inductive sensor

The sensor is mounted opposite a metal target (ferromagnetic material) made up of teeth and pits. The physical principle behind the production of an inductive voltage is based on the variation of the magnetic field over time. The speed sensor scans the teeth of the flywheel ring gear and provides one output pulse per tooth.



1- electrical connection, 2- sensor housing, 3- motor housing, 4 - gasket, 5- magnet, 6 - Gap, 7- gear wheel

Figure II.3. The physical principle of detection

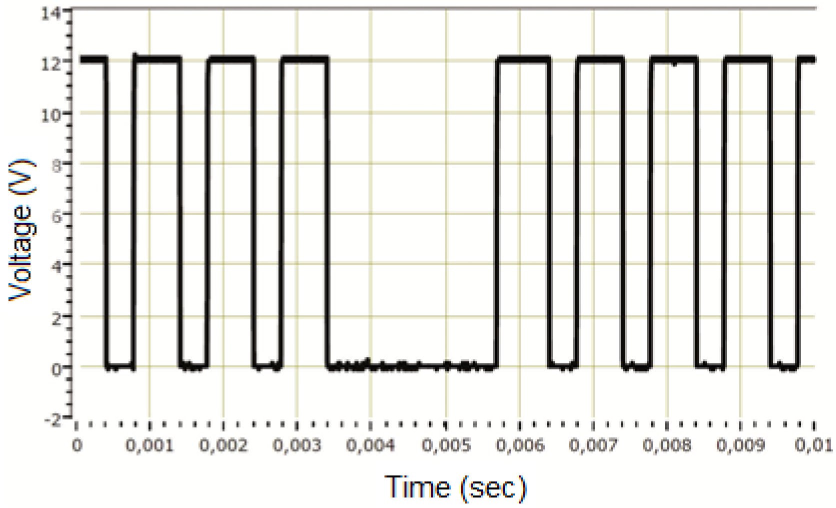


Figure II.4.Signals emitted from the sensor (tooth signal)

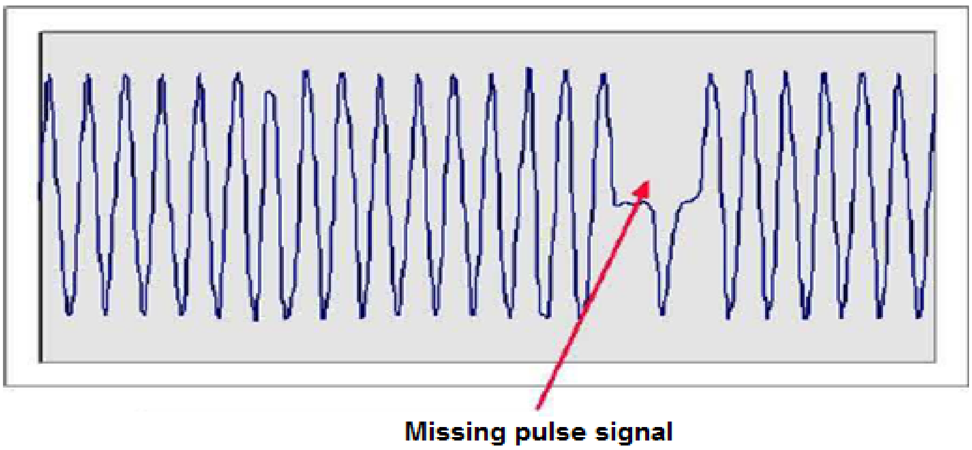


Figure II.5.The detected signal of missing teeth

2.1. Operating Principle

The engine speed sensor consists of a magnetic core and a coil. When the flywheel teeth move past the sensor, a variation in the magnetic field is created, which induces an alternating voltage (sinusoidal signal) in the coil, the frequency and amplitude of which are proportional to the engine speed. It is attached to the timing belt, but more commonly to the clutch housing, and positioned opposite a 60-tooth ring gear; two of these have been removed for TDC recognition.

The resistance of this sensor can vary from 360 to 500 ohms. It is equipped with a 3-pin brown connector, a 2-pin black connector, or a 3-pin gray connector on diesel engines with a resistance of 110 ohms.

The voltage of this sensor can be measured in the alternating mode; it must be between 4 and 9 volts.

2.2. Role in Automobiles

Speed sensors play several essential roles in the proper functioning of automobiles, including:

2.2.1. Transmission System

In vehicles with automatic or manual transmissions, speed sensors provide information about the vehicle's speed to the transmission control system. This information is used to adjust gear changes and engine speed based on the vehicle's velocity, ensuring smooth transmission operation.

2.2.2. ABS Braking System

In anti-lock braking systems (ABS), speed sensors monitor the rotational speed of each wheel. This data is used to detect any wheel lock-up during braking and adjust brake pressure to prevent the wheels from locking, which improves the vehicle's stability and control during emergency braking.

2.2.3. Traction Control System

Speed sensors are also used in traction control systems to monitor the rotational speed of the wheels and detect any slippage or loss of traction. Based on this information, the system can adjust engine power or apply selective braking to maintain traction and vehicle stability on slippery surfaces or in difficult driving conditions.

2.2.4. Electronic Stability Program (ESP)

Speed sensors also contribute to the function of the Electronic Stability Program by monitoring the rotational speed of each wheel and detecting any deviation from the vehicle's expected movement. The system can then intervene by applying selective braking to certain wheels to correct the vehicle's trajectory and prevent skidding or loss of control.

2.3. Technologies and Techniques for Speed Measurement

In automotive applications, speed measurement is crucial for many systems and features, ranging from transmission control to the anti-lock braking system (ABS).

2.3.1. Wheel Speed Sensors

- ✓ These sensors detect the rotation of the vehicle's wheels. They typically use magnets and magnetic field sensors to measure the rotational speed of each wheel.
- ✓ Wheel speed sensors are essential for anti-lock braking systems (ABS), traction control systems, and electronic stability control systems (ESP), as they detect any speed difference between the wheels, which can indicate slippage or a loss of traction.

2.3.2. Transmission Speed Sensors

- ✓ These sensors measure the rotational speed of the driveshaft or the transmission's output shaft.
- ✓ They are used in automatic transmissions to select the appropriate gear ratio based on vehicle speed, as well as in engine control systems to regulate engine speed and optimize vehicle performance and efficiency.

2.3.3. Ultrasonic Speed Sensors

- ✓ Ultrasonic speed sensors measure vehicle speed using high-frequency sound waves.
- ✓ These sensors are often used in adaptive cruise control systems, where they measure the relative speed of other vehicles on the road.

2.3.4. GPS Speed Sensors

- ✓ GPS speed sensors use satellite signals to determine the vehicle's speed.

- ✓ They are often integrated into navigation devices and vehicle tracking systems to provide accurate and real-time speed information.

2.3.5. Hall Effect Speed Sensors

- ✓ These sensors detect changes in a magnetic field and are used to measure the rotational speed of magnetic components, such as the camshaft or crankshaft.
- ✓ They are commonly used in engine control systems to monitor engine speed and synchronize ignition timing and fuel injection.

The Hall effect was discovered in 1879 by the American physicist Edwin Hall. It is one of a set of galvano-magnetic phenomena that are observed in a solid subjected to the action of an electric field and magnetic induction.

Notice :

1. The sensor cable must be shielded.
2. Electronic component cables must not run too close to other power cables on the machine or vehicle.
3. Maintain a sufficient distance from radio-frequency systems.
4. If using longer cables (5 m), shield each frequency signal cable separately.

3. Flow Sensor

3.1. Flow Rate

Flow rate is usually measured indirectly by measuring the average velocity across a known cross-section. The flow rate measured by this indirect method is the volumetric flow rate (QV):

$$QV=S\cdot V$$

- S is the cross-sectional area of the pipe in m^2
- V is the average velocity of the fluid in m/s

The volumetric flow rate (Qv) is the volume of fluid that flows per unit of time (in m3/s).

The mass flow rate (Qm) is the mass of fluid that flows per unit of time (in kg/s).

3.2. The Flow Sensor

- Flow sensors are electronic devices designed to measure the speed or flow rate of a fluid, such as air, fuel, or a liquid, moving through a system. These sensors convert the fluid's quantity into an electrical signal that can be interpreted by other vehicle components.
- Flow sensors or flow meters are devices intended to measure the linear, non-linear, mass, or volumetric flow rate of a fluid, whether liquid or gas.

Note:
Choosing a flow meter is not a simple task. To make the correct choice, a multitude of parameters must be taken into account. It is therefore necessary first and foremost to precisely define your own requirements, the constraints imposed by the fluid to be measured, and the characteristics of the environment. Afterward, the constraints related to the various possible devices are added.

3.3. Operating Principle of the Flow Meter

The detection principle is based on measuring the force generated by the intake airflow, which acts on an air-vane sensor and opposes the restoring force of a spring. The air-vane is displaced as the air volume increases, and the free passage section widens by following the specific profile of the measurement channel.

The flow meter is responsible for determining the mass flow rate of the intake air in order to optimize the amount of fuel to be atomized by the injectors.

The angular position of the air-vane sensor is converted into an electrical voltage by a potentiometer.

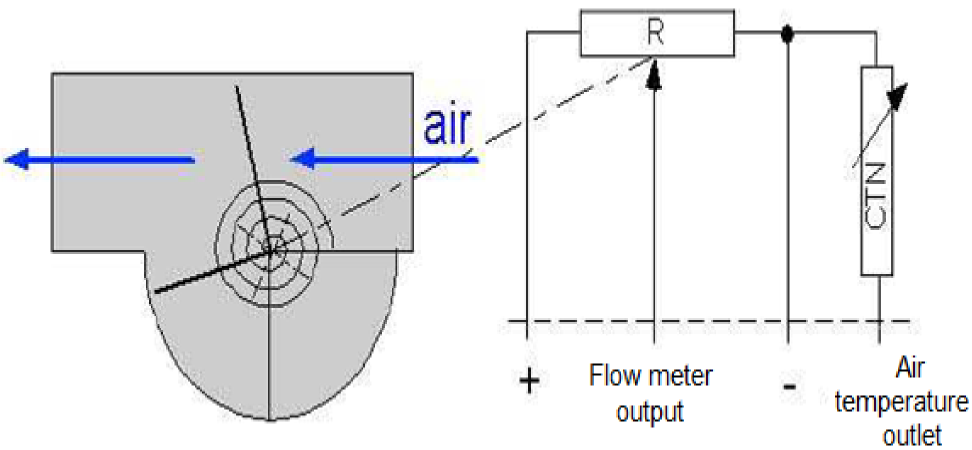


Figure II.6. Angular position of the air flow meter probe flap

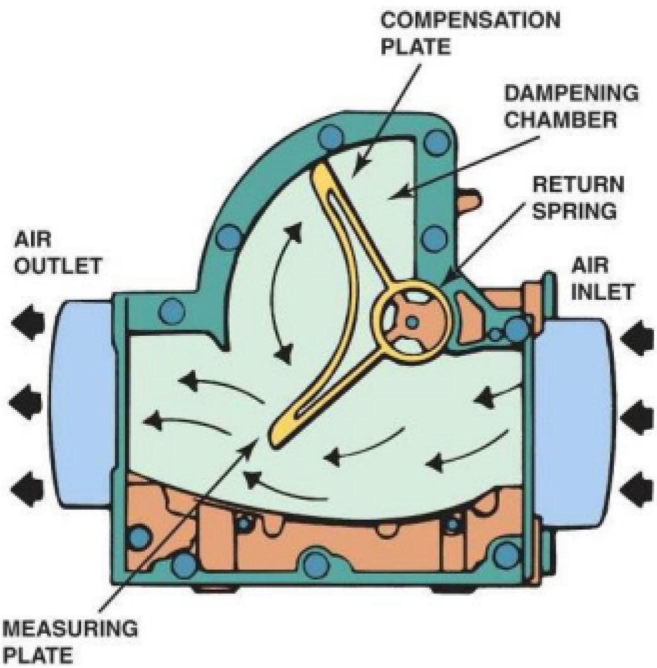


Figure II.7. Air flow meter

- The flow meter is responsible for determining the mass flow rate of the intake air in order to best adjust the amount of fuel to be atomized by the injectors.
- The flow meter is supplied with 5V; the movement of the measuring flap is integral to the slider of a potentiometer. This flow meter is equipped with an NTC (Negative Temperature Coefficient) resistor that measures the temperature of the intake air.

3.4. Types of Flow Sensors Used in Automobiles

3.4.1. Mass Air Flow (MAF) Sensors

These sensors measure the mass of air entering the engine. This information is crucial for the Engine Control Unit (ECU) to calculate the correct amount of fuel to inject, ensuring an optimal air-fuel ratio.

3.4.2. Fuel Flow Sensors

These sensors measure the flow rate of fuel to the engine. They can be used to monitor fuel consumption and detect potential issues in the fuel delivery system.

3.4.3. Other Types of Flow Sensors

This category includes sensors that measure the flow of other fluids in the vehicle, such as:

- ✓ **Coolant Flow Sensors**: Used to monitor the flow of coolant through the engine's cooling system to prevent overheating.
- ✓ **Oil Flow Sensors**: Used to monitor oil flow to critical engine components.

- ✓ **Exhaust Gas Recirculation (EGR) Sensors**: Measure the flow of exhaust gases being recirculated back into the engine to reduce emissions.

3.5. Role in Automobiles

Flow sensors are used in various automotive systems to monitor and control the flow of fluids. Their specific role varies depending on the type of sensor and the system they are integrated into. Here are some of the main roles of flow sensors in automobiles:

3.5.1. Air Intake System

In internal combustion engines, mass air flow sensors measure the amount of air entering the engine. This information is used by the engine management system to calculate the amount of fuel to inject, ensuring an optimal air-fuel mixture for efficient combustion and reduced emissions.

3.5.2. Fuel System

Fuel flow sensors measure the amount of fuel that enters the engine. This data allows the fuel injection system to precisely regulate the amount of fuel injected, ensuring efficient combustion and optimal fuel economy.

3.5.3. Engine Cooling

Some vehicles are equipped with coolant flow sensors to monitor the flow of coolant circulating through the engine. This allows the cooling system to maintain the engine temperature within safe limits, preventing overheating and potential damage.

3.5.4. Transmission and Hydraulic Systems

In vehicles with automatic transmissions or hydraulic systems, flow sensors are used to monitor the flow of hydraulic fluid. This ensures smooth operation and optimal performance of these systems.

3.5.5. Emissions Control

Flow sensors also play an important role in emissions control by measuring the amount of air entering the engine and monitoring potential fuel leaks, thereby helping to reduce a vehicle's polluting emissions.

3.6. Flow Measurement Technologies and Techniques

3.6.1. Coriolis effect Technology

This technology utilizes the principle of the Coriolis effect, which describes the apparent force felt by a moving object in a rotating reference frame. In Coriolis effect flow sensors, the fluid flows through a vibrating or rotating tube. As the fluid changes direction while passing through the tube, it generates a force that affects the tube's movement. This force is measured and used to determine the fluid's flow rate.

3.6.2. Ultrasonic Technology

Ultrasonic flow sensors measure flow using ultrasonic waves. These waves are emitted through the fluid and reflected by the moving particles within it. The velocity of the particles modifies the frequency and phase of the reflected ultrasonic waves, which allows the sensor to calculate the fluid's flow rate based on these changes.

3.6.3. Hot-Wire Technology

Hot-wire flow sensors measure flow by heating a thin wire placed in the fluid's path. The convection of the fluid around the hot wire causes it to cool, which changes the wire's electrical resistance. By measuring the variation in the hot wire's electrical resistance, the sensor can determine the fluid's velocity and calculate the corresponding flow rate.

3.6.4. Electromagnetic Technology

Electromagnetic flow sensors utilize the principle of Faraday's Law, which describes the electromotive force induced in a conductor moving through a magnetic field. In these sensors, the fluid flows through a conduit containing a magnetic field. The electromotive force induced by the fluid's movement is measured and used to calculate the flow rate.

3.6.5. Paddle or Turbine Technology

In paddle or turbine flow sensors, the fluid causes a paddle or turbine inside the sensor to rotate. The rotational speed of the paddle or turbine is proportional to the fluid's flow rate. A rotational speed sensor then measures this speed and converts it into a flow measurement.

NOTE: *Flow sensors are critical components in automobiles, helping to ensure the efficient, economical, and environmentally friendly operation of the vehicle's various systems.*

4. Acceleration sensors

Acceleration sensors (accelerometers) are electronic devices that detect and measure changes in a vehicle's speed, whether linear (movement in a specific direction) or angular (rotation around an axis). These sensors convert speed changes into electrical signals that can be interpreted by the vehicle's control systems.

Figure II.8. Acceleration sensor

4.1. Operating Principle

The acceleration sensor in an automobile relies on the use of components that are sensitive to mechanical forces or deformations.

- **Sensitive Components:** Acceleration sensors generally use force-sensitive elements, such as piezoelectric elements or mechanical microstructures (like MEMS). These components react to changes in acceleration by generating an electrical signal that is proportional to the applied force.
- **Inertial Force Principle**: When a vehicle accelerates, decelerates, or undergoes a lateral acceleration, an inertial force is exerted on the components of the acceleration sensor. This inertial force deforms the sensor's sensitive elements, which generates an electrical signal proportional to the applied acceleration.
- **Electrical Signal Measurement:** The electrical signal generated by the acceleration sensor is measured and converted into a numerical value representing the acceleration in a given direction. This signal can be

electronically processed by integrated circuits to amplify, filter, and convert it into a form usable by the vehicle's electronic systems.

- **Sensor Orientation:** The design and orientation of the acceleration sensor determine the directions in which it measures acceleration. For example, a sensor mounted on the vehicle's longitudinal axis will primarily measure front and rear accelerations, while a sensor mounted on the transverse axis will measure lateral accelerations.
- **Integration into Automotive Systems: Acceleration sensors** are integrated into many automotive systems, such as passive safety systems (airbag deployment), stability control systems (ESP), traction control systems, advanced driver-assistance systems, etc. These systems use the information provided by the acceleration sensors to make real-time decisions and improve vehicle safety and performance.

4.2. Role in Automobiles

Acceleration sensors play a crucial role in several aspects of vehicle operation and safety:

- **Passive Safety Systems**

Acceleration sensors are used in airbag deployment systems to detect the rapid decelerations associated with a collision. When a collision is detected, the sensors send a signal to the airbag control units to deploy the airbags appropriately and protect the vehicle's occupants.

- **Stability and Dynamic Control Systems**

Acceleration sensors are used in Electronic Stability Control (ESP) systems to monitor the vehicle's lateral and longitudinal movements. By detecting deviations between the vehicle's actual and expected behavior, the sensors allow the ESP system to intervene by selectively applying the brakes on certain wheels or adjusting engine power to correct the vehicle's trajectory and prevent skidding or loss of control.

- **Engine Control Systems**

Acceleration sensors can also be used in engine control systems to measure the vehicle's acceleration and, as a result, adjust the air-fuel mixture, ignition timing, and other engine parameters to optimize vehicle performance and efficiency.

- **Advanced Driver-Assistance Applications**

In vehicles equipped with advanced driver-assistance systems, such as adaptive cruise control and lane-keeping assist, acceleration sensors are used to detect changes in vehicle speed and acceleration, allowing the system to automatically regulate speed and direction based on driving and traffic conditions.

4.3. Acceleration Measurement Technologies and Techniques

The main technologies and techniques for measuring acceleration used in vehicles:

- **MEMS Accelerometers (Micro Electro-Mechanical Systems)**
  - MEMS accelerometers are miniaturized sensors that measure acceleration using mechanical microstructures and integrated electronic circuits.
  - In automobiles, these accelerometers are used to detect the vehicle's linear movements, such as forward, backward, lateral, or vertical accelerations. They are widely used in airbag deployment systems, Electronic Stability Control (ESP) systems, and advanced driver-assistance systems.
- **Piezoelectric Accelerometers**
  - Piezoelectric accelerometers use the principle of piezoelectricity, where piezoelectric materials generate an electrical charge in response to mechanical stress.
  - These accelerometers are used in automotive applications to measure linear accelerations and vibrations of the vehicle. They are commonly used in stability control and traction control systems, as well as in vehicle vibration diagnostic systems.
- **Differential Pressure Sensors**
  - Differential pressure sensors measure the pressure difference between two given points. In an automotive context, these sensors can be used to measure the vehicle's longitudinal and lateral accelerations.

- For example, in traction control systems, these sensors can be used to measure the pressure difference between the left and right tires, which helps to detect differences in traction and automatically correct the power distribution between the wheels.

- **GPS Systems (Global Positioning System)**
  - GPS systems can be used to estimate a vehicle's acceleration based on changes in position and speed over time.
  - While less precise than other methods of acceleration measurement, GPS systems can be useful for monitoring driver performance and providing information on vehicle acceleration in certain situations.

Note:
Acceleration sensors are essential components in automobiles, contributing to vehicle safety, stability, and performance by detecting movements and changes in vehicle speed and allowing control systems to react appropriately to changing driving conditions.

5. Temperature Sensor

Temperature sensors are sensory devices used to detect and measure temperature variations in liquids or environments both inside and outside the vehicle. They convert these variations into electrical or electronic signals that can be interpreted by other electronic systems in the vehicle.

They are generally thermocouples (an association of two metals that provides a voltage dependent on temperature) or variable resistors:

- **NTC** (Negative Temperature Coefficient): The resistance decreases as the temperature increases.
- **PTC** (Positive Temperature Coefficient): The resistance increases as the temperature increases.

5.1. Operating Principle

The temperature sensor is based on different types of technologies depending on the specific temperature measurement needs.

5.1.1. Thermistor

Thermistors are resistors whose value changes with temperature. Negative Temperature Coefficient (NTC) thermistors are often used, which have a resistance that decreases as the temperature increases. When a thermistor based temperature sensor is exposed to a temperature, its resistance changes accordingly. This resistance variation is measured electronically and converted into a temperature value.

Figure II.9. Temperature sensors (Thermistor)

5.1.2. Semiconductor Temperature Sensor

Semiconductor temperature sensors use semiconductor materials whose electrical properties vary with temperature. These sensors convert the change in the semiconductor's electrical properties into a measurable temperature value.

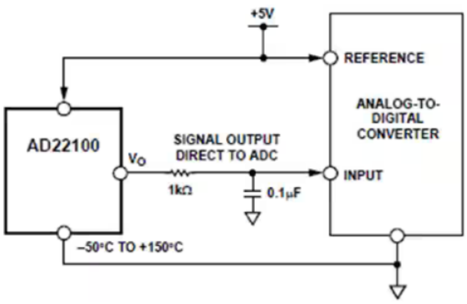


Figure II.10. Semi-conductor temperature sensor

5.1.3. Platinum Resistance Temperature Detector (RTD)

RTDs are platinum resistors whose resistance increases linearly with temperature. They offer high precision over a wide temperature range.

RTD temperature sensors are often used in automotive applications that require high precision, such as measuring the temperature of the coolant or the engine.

Once the variation of the electrical quantity (resistance, voltage, etc.) is measured, it is converted into a temperature value using a dedicated electronic circuit. This temperature value is then used by the vehicle's various control and monitoring systems to make decisions based on the operating conditions.

Figure II.11. Platinum resistance temperature sensor (RTD)

5.2. Role in Automobiles

Temperature sensors play a crucial role in many aspects of automotive vehicles, including:

5.2.1. Engine Monitoring

Temperature sensors are used to monitor the engine coolant temperature. They allow the engine management system to regulate the cooling system's operation to maintain the engine at an optimal operating temperature and prevent overheating.

5.2.2. Emissions Control

Temperature sensors are also used to monitor exhaust gas temperature. This information is used by the emissions control system to optimize the operation of the exhaust after-treatment system, such as the catalytic converter, to reduce polluting emissions.

5.2.3. Passenger Comfort

Temperature sensors can be used to monitor the temperature inside the vehicle and control the automatic air conditioning or heating system to maintain a comfortable temperature for passengers.

5.2.4. Safety Systems

Some temperature sensors are used in safety systems, such as airbag deployment systems. They can monitor the temperature of the airbag or its environment to ensure that the airbags deploy appropriately in various temperature conditions.

5.2.5. Fluid and Component Monitoring

Temperature sensors are used to monitor the temperature of fluids, such as engine oil, transmission fluid, or brake fluid. They help to identify abnormal conditions, such as overheating or a drop in temperature, which could indicate a potential problem in the system.

Table II.1. Characteristic temperatures of a motor vehicle

No	Measuring point	rang °C	
		Min	Max
01	Air intake / supercharging	**- 40**	**170**
02	Ambient air	**-40**	**60**
03	Interior	**-20**	**80**
04	Ventilation/ Heating	**-20**	**60**
05	Evaporator (Air Conditioner)	**- 10**	**50**
06	Cooling water	**- 40**	**130**
07	Engine oil	**- 40**	**170**
08	Battery	**- 40**	**100**
09	Fuel	**- 40**	**120**
10	Tire air	**- 40**	**120**
11	Exhaust gas	**100**	**1000**
12	Brake caliper	**- 40**	**2000**

6. Pressure sensors

Automotive pressure sensors are widely used in engine systems, air conditioning systems, braking systems, fuel control systems, and exhaust after treatment systems. Installed on the relevant system or pipeline, they detect pressure (and temperature) information in real time. The measured pressure (and temperature) signals are transmitted to the vehicle control system, ensuring efficient, stable, and reliable vehicle operation.

Figure II.12.Pressure sensor in the automobile

TDK's innovative tank pressure sensor design takes a different approach: All plastics and elastomers that come into direct contact with fuels are replaced with extremely durable glass-based materials that are matched in terms of thermal expansion (Figure 2.14). Unlike elastomers, these materials do not swell, shrink or become brittle, thus eliminating inaccurate pressure measurements due to signal drift or leakage.

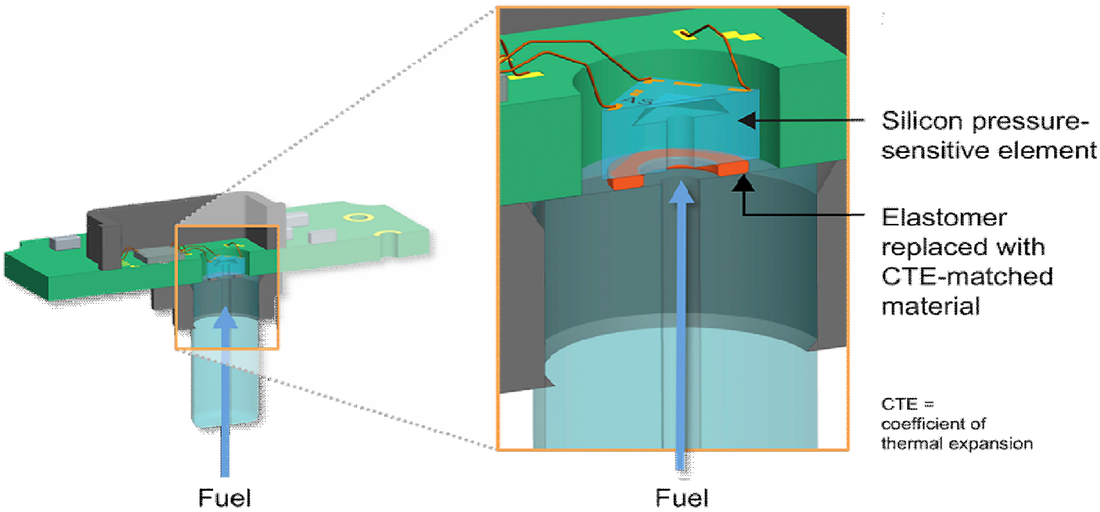


Figure II.13.Working principle of pressure sensor

The advanced pressure sensor platform for fuel line and tank applications eliminates swelling of materials and interconnections and enables flexible integration in applications with temperatures up to 125 °C. All plastics and elastomers that come into contact with fuel are replaced with durable CTE-matched materials.

As a consequence, this sensor technology offers a high resistance against all fuels and provides an accurate signal with a narrow tolerance of less than ±1% FS over a wide temperature range of -40 °C to +125 °C, even at temperature changes within a certain time period. TDK's pressure sensor technology thus represents an advanced sensor platform for multiple fuel applications and enables a wide variety of application-specific options for housings and connectors.

6.1. Features

- **Sensor:** High-sensitivity chips based on piezo-resistor MEMS technology.
- **Operating pressure range:** -1.2 to 50 bar or customer-specific
- **Typical temperature range**: -40 to 150°C
- **Typical signal output:** Analog or SENT interface
- **Typical power supply**: 5 V
- **Connector**: Customer-specific
- Designed for harsh environments with excellent long-term stability

6.2. Applications in Automobiles

6.2.1. Engine oil pressure sensor

Detects engine oil pressure, This sensor ensures the cooling, lubrication, cleaning, and sealing of the engine and plays an essential role in its proper functioning.

6.2.2. TMAP, MAP application

Installed in gasoline injection systems, it measures the variations in absolute pressure and temperature in the intake manifold to allow the ECU (Electronic Control Unit) to evaluate the engine's load state.

6.2.3. Activated carbon filter pressure sensor

Installed on a device for adsorbing and desorbing fuel vapors (the activated carbon filter), it detects the internal absolute pressure and allows the ECU to evaluate the atmospheric pollution generated by the vehicle while also improving energy efficiency.

6.2.4. Differential pressure sensor

This sensor detects the pressure on either side of the gasoline particulate filter installed in the exhaust system. It reflects the condition of the particulate filter and plays an important role in the system's regeneration and diagnosis.

6.2.5. Fuel tank/fuel vapor pressure detection

The evaporative fuel leak pressure sensor, mounted on the fuel line or directly on the tank, detects the amount of possible leakage in the evaporative fuel control system and outputs the signal for on-board diagnostics.

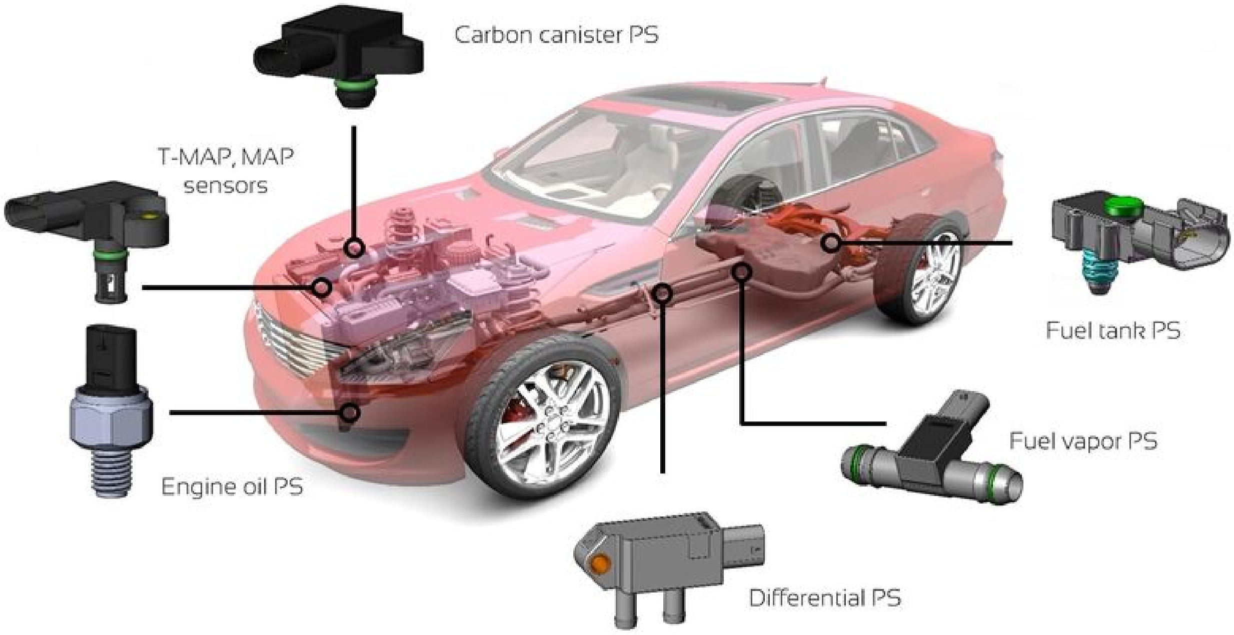


Figure II.14.Different pressure sensor locations in the automobile

7. Proximity Sensors

Proximity sensors are increasingly used in modern motor vehicles. Their primary function is to detect the proximity of objects or obstacles around the vehicle, thereby improving safety, convenience, and driving comfort. This course will explore the importance of proximity sensors in automobiles, their operating principles, applications, and technologies.

Figure II.15. Proximity sensor

7.1. <u>Principles of Proximity Sensor Operation</u>

Proximity sensors use various technologies to detect the presence of objects near a vehicle. The most common technologies used in automobiles are:

7.1.1. **Ultrasonics**

Ultrasonic sensors emit high-frequency sound waves and detect reflections from surrounding objects. The distance between the sensor and the object is calculated by measuring the time elapsed between the emission of the ultrasonic signal and the reception of its echo.

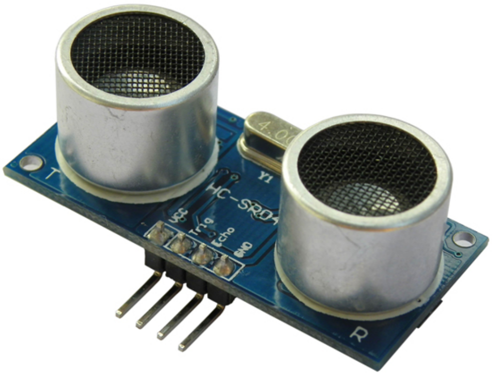


Figure II.16. Ultrasonic proximity sensor

7.1.2. **Infrared sensors**

These sensors emit infrared beams and measure the amount of infrared light reflected by surrounding objects. Detecting a change in the amount of reflected infrared light indicates the presence of an object nearby.

Figure II.17. Sensor emitting infrared beams

7.1.3. Cameras

Vehicle-mounted cameras are used to detect objects and obstacles by analyzing images in real time. Computer vision systems can identify and track objects in the camera's field of view to provide warnings to the driver or activate parking assistance systems.

Figure II.18. Vehicle camera

7.2. <u>Applications of Proximity Sensors</u>

Proximity sensors are used in many automotive systems and components to improve safety and convenience.

7.2.1. Parking Assist Systems (PAS)

Proximity sensors detect obstacles while parking and provide the driver with visual and audible warnings to avoid collisions.

7.2.2. Collision Warning Systems

Proximity sensors are used to detect the closeness of vehicles or obstacles and warn the driver of an imminent collision risk.

7.2.3. Adaptive Cruise Control (ACC)

Proximity sensors monitor the distance to vehicles ahead and automatically adjust the vehicle's speed to maintain a safe following distance.

7.2.4. Blind Spot Detection Systems

Proximity sensors detect the presence of vehicles in the driver's blind spots and provide visual or audible warnings to prevent dangerous lane changes.

8. Gyroscopic Sensors

8.1. Definitions

- A gyroscopic sensor, often simply referred to as a gyroscope, is a device used to measure or detect the orientation or changes in orientation of an object. It relies on the principles of angular momentum conservation and gyroscopic precession to detect rotational movements.
- Gyroscopic sensors are widely used in many fields, including aviation, astronautics, the automotive industry, maritime navigation, drones, consumer electronics (such as smart phones and game consoles), and many others. They play a crucial role in maintaining stability, navigation, motion detection, and many other applications requiring accurate detection of spatial orientation.
- Gyroscopic sensors play an essential role in improving the safety, stability, and accuracy of control and driver assistance systems in modern motor vehicles.

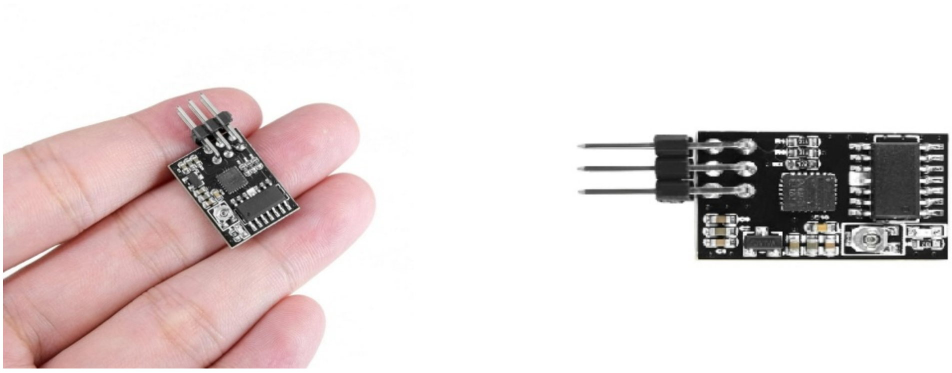


Figure II.19. Compact Gyroscope Module Mini Gyro Sensor

8.2. Operation of the gyroscopic sensor

The operation of a gyroscopic sensor is based on the principles of conservation of angular momentum and gyroscopic precession.

- **Conservation of Angular Momentum**

  According to this principle, a rotating object maintains its angular momentum that is, its tendency to continue spinning in the same direction and at the same rate unless an external force acts upon it.

- **Gyroscopic Precession**

  When a force is applied to a spinning gyroscope, instead of moving in the direction of the force like a non-gyroscopic object would, the gyroscope will instead turn around an axis perpendicular to the applied force. This movement is called precession.

The function of a gyroscopic sensor involves detecting this processional movement to determine changes in the orientation of the object to which it's attached. Here is a more detailed explanation of this process:

- **Sensor Construction**

  A gyroscopic sensor typically consists of a rotor mounted on an axis that can rotate freely in one or more directions. This rotor is often referred to as the gyroscope's moving part.

- **Motion Detection**

  When the object to which the gyroscope is attached undergoes a rotation, the gyroscope's moving part maintains its orientation in space, in accordance with the principle of conservation of angular momentum. This creates a processionals force that is perpendicular to both the applied force and the axis of rotation.

- **Precession Measurement**

  Gyroscopic sensors use devices such as micro-electromechanical systems (MEMS) to measure these processional movements. These devices are able to detect tiny changes in the gyroscope's orientation and convert them into electrical signals.

- **Data Interpretation**

  The electrical signals generated by the gyroscopic sensor are then interpreted by an electronic system to determine the object's orientation relative to a given reference. This information can be used to control various systems, such as stabilizers, navigation devices, virtual reality systems, and more.

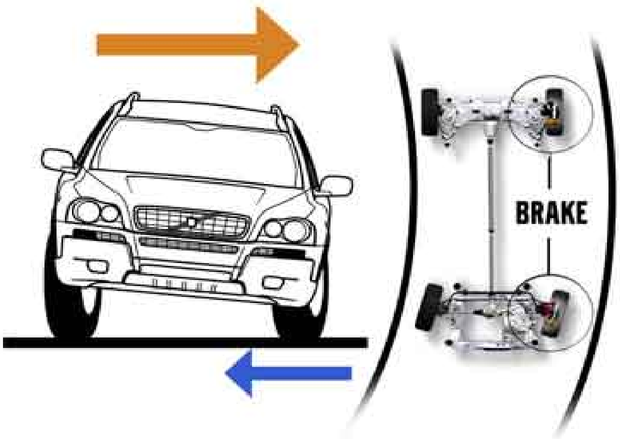


Figure II.20. Roll stability control

The electronic program to limit the risk of a rollover this system uses a gyroscopic sensor to measure the vehicle's roll speed and angle (Figure 2.20). If the calculated angle is so significant that there is a clear risk of a rollover, the ESP system is activated to reduce engine power and brake one or more wheels as needed until the car under steers and stability is restored.

8.3. Gyroscopic Sensor Technologies

There are several types of gyroscopic sensor technologies each with its down specific advantages, disadvantages, and applications.

8.3.1. MEMS (Micro-Electro-Mechanical Systems) Gyroscopes

- MEMS gyroscopes are among the most commonly used gyroscopic sensors due to their small size, low cost, and low power consumption.
- They work by measuring capacitive variations or mechanical displacements induced by the rotation of the gyroscope's microscopic structure.
- MEMS gyroscopes are widely used in consumer electronics like smart phones, tablets, and gaming consoles, as well as in various industrial and automotive applications.

8.3.2. Fiber Optic Gyroscopes

- These gyroscopes leverage the properties of light as it travels through an optical fiber.
- They measure the phase shifts caused by the effects of the optical fiber's rotation on the light passing through it.
- Fiber optic gyroscopes offer high precision and great stability, making them ideal for high-performance applications such as inertial navigation in aerospace and maritime navigation.

8.3.3. Ring Laser Gyroscopes (RLGs) and Fiber Optic Gyroscopes (FOGs)

- Laser gyroscopes use optical effects to measure rotation.
- RLGs measure the differences in the resonance frequency of a laser beam in a rotating closed loop, while FOGs measure the phase changes of light in a rotating fiber optic loop.
- They offer excellent precision and long-term stability but are generally more expensive and bulkier than MEMS or standard fiber optic gyroscopes.

8.3.4. Magneto resistive Gyroscopes

- These gyroscopes utilize the changes in the electrical resistance of magneto resistive materials as a function of rotation.

- They are often used in applications where miniaturization and low power consumption are essential, such as in portable devices and drones.

8.4. Automotive Applications of Gyroscopic Sensors

8.4.1. Electronic Stability Control (ESC) / Dynamic Stability Control (DSC) Systems

- Gyroscopic sensors are used to detect a vehicle's yaw movements (rotation around the vertical axis) and help maintain stability in the event of a skid or loss of control.
- The ESC/DSC system uses information from these sensors to selectively apply the brakes and/or reduce engine power. This corrects the vehicle's trajectory and prevents understeer or oversteers.

8.4.2. Traction Control Systems (TCS)

- Gyroscopic sensors detect a vehicle's pitch movements (rotation around the longitudinal axis) to help maintain wheel grip.
- They do this by regulating engine power and/or selectively applying the brakes to prevent wheel spin.

8.4.3. Roll and Pitch Management Systems

- Gyroscopic sensors measure a vehicle's roll (rotation around the transverse axis) and pitch movements.
- This information is used to dynamically adjust the suspension and power steering, reducing roll and pitch. This improves driving comfort and road Handling.

8.4.4. Parking Assistance and Blind Spot Monitoring Systems

- Some vehicles use gyroscopic sensors to measure the steering angle of the wheels, assisting drivers with parking maneuvers by providing visual or audible cues.
- Gyroscopic sensors can also be used in blind spot monitoring systems to detect vehicles approaching from the sides and warn the driver of potential danger.

8.4.5. Navigation and Localization Systems

- Gyroscopic sensors can be combined with other sensors, like accelerometers and GPS systems, to provide accurate information on a vehicle's orientation and movement.

- This information is used to improve the precision of integrated navigation and driver assistance systems, including inertial navigation in areas with weak or no GPS signal.

8.5. Gyroscopic Sensor Characteristics

The characteristics of gyroscopic sensors used in automotive applications can vary based on factors such as precision, size, power consumption, robustness, and cost.

- **Precision**

This is a crucial characteristic for automotive gyroscopic sensors because it determines the system's ability to accurately detect rotational movements and provide reliable information for control and driver-assistance systems.

- **Responsiveness**

Responsiveness refers to how quickly a gyroscopic sensor can detect orientation changes and provide real-time data. High responsiveness is important to ensure quick and accurate reactions from stability control and driver-assistance systems.

- **Long-Term Stability**

This refers to the sensor's ability to maintain its precision and calibration over an extended period. It's essential that the sensor's performance characteristics remain consistent over time to ensure the proper functioning of the vehicle's onboard systems.

- **Size and Integration**

The size of the gyroscopic sensor is important, especially in cars where space is often limited. Compact and easy-to-integrate gyroscopic sensors allow for simple installation without compromising the vehicle's design or ergonomics.

- **Power Consumption**

The power consumption of a gyroscopic sensor is a critical factor, especially in automobiles where energy efficiency is important. Low-power sensors help reduce the load on the vehicle's electrical system and extend battery life.

- **Robustness and Reliability**

Gyroscopic sensors must be robust and reliable to function consistently in the harsh automotive environment, which includes vibrations, shocks, temperature variations, and various weather conditions.

- **Cost**

Cost is also an important factor, especially in the context of large-scale automotive manufacturing. Affordable gyroscopic sensors help make control and driver-assistance systems more accessible to consumers.

9. The Oxygen Sensor (Lambda Probe)

9.1. Definition

The lambda sensor, also known as an oxygen sensor, is a crucial component of modern engine management systems in motor vehicles. It plays a vital role in controlling emissions and fuel consumption by measuring the amount of oxygen present in the exhaust gases.

Figure II.21.The lambda probe

The lambda sensor is usually located in the exhaust system, either upstream or downstream of the catalytic converter. It continuously monitors the percentage of oxygen in the exhaust gases and sends this information to the engine control module (ECM/ECU).

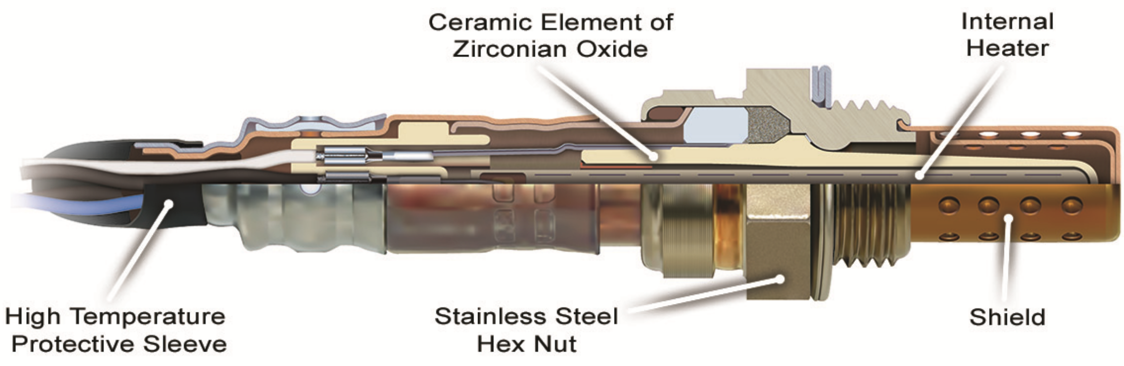


Figure II.22.Composition of the Lambda probe

9.2. The Mixture

The ideal air/fuel mixture ratio is **14.7** grams of air to **1** gram of gasoline. This is called a «Stœchiometric" mixture, and it ensures the perfect combustion of the fuel.

- **Excess air or a lack of fuel (lean mixture)**: will increase the amount of residual oxygen after combustion. This means there's too much air to burn the available fuel, or not enough fuel to be burned by the air.
- **A lack of air or an excess of fuel (rich mixture):** will reduce the amount of residual oxygen after combustion. This means there isn't enough air to burn the fuel, or there is too much fuel for the amount of air available.

Note:

- This process, of course, requires a dedicated electronic control device called a lambda sensor.

- The air/fuel mixture is characterized by the "air coefficient" λ (Lambda).

9.3. Operating Principle

The lambda sensor operates on the principle of electrochemical chemistry. It consists of a heating element and a layer of porous ceramic material coated with platinum. At a high operating temperature, oxygen in the exhaust gases reacts with the platinum, causing a change in electrical voltage between two electrodes within the sensor.

9.3.1. Lambda Sensor Signal

The lambda sensor's signal varies depending on the air-fuel mixture:

- If the mixture is rich in fuel (too much fuel relative to oxygen), the lambda sensor's signal will be low.

- If the mixture is lean (too much oxygen relative to fuel), the signal will be high.
- A Stœchiometric (ideal) mixture will produce a signal that oscillates around a medium value.

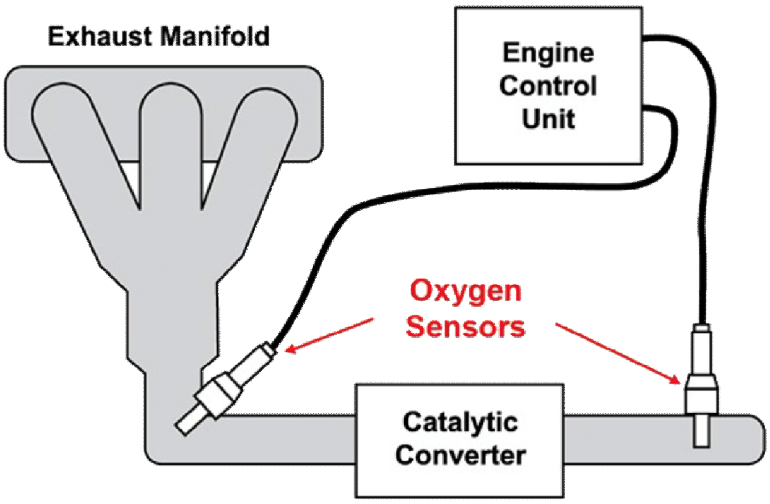


Figure II.23. Produces voltage in relation to the amount of oxygen in the exhaust

9.3.2. Measurement principle

A different oxygen concentration on both sides of the cell creates tension.

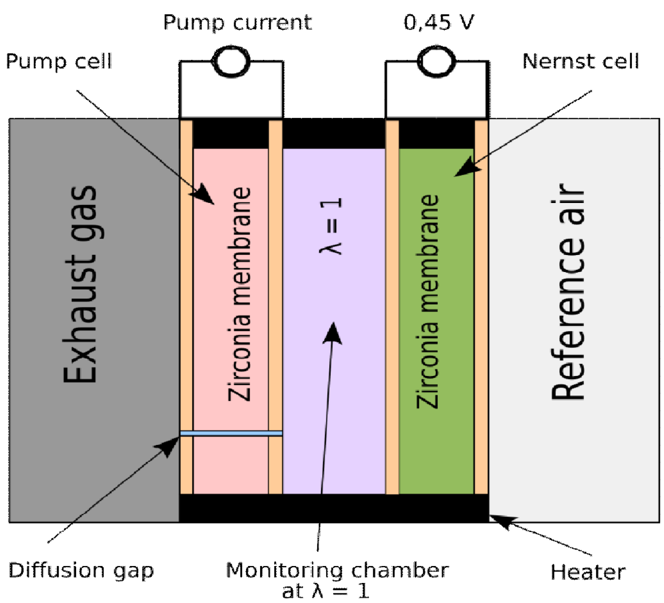


Figure II.24. The detection cell

- The sensor is heated by a resistor (it only works above 350°C).

- The signal varies between lean (0.1V) and rich (0.8V) approximately, in line with the richness regulation.

- **Why is a Lambda Sensor Necessary?**

Due to stricter legislation regarding the reduction of exhaust gases, exhaust gas after-treatment techniques have also improved. To ensure an optimal conversion rate for the catalytic converter, optimal combustion is necessary. This is achieved with a mixture composition of **14.7 kg** of air for every **1 kg** of fuel (a Stœchiometric mixture). This optimal mixture is designated by the Greek letter lambda (λ). The ratio between the theoretically required air and the air actually supplied is expressed as lambda:

$$\lambda = \frac{\text{Actual air supply}}{\text{Theoretically required air quantity}} = \frac{14.8kg}{14.8kg} = 1$$

λ < 1: Indicates a lack of air or a "rich" mixture.

λ > 1: Indicates an excess of air or a "lean" mixture.

- **The Lambda Sensor's Measurement Range**
  - A lower voltage (approximately 0.1 to 0.3 volts) indicates an oxygen-rich mixture, meaning there's an excess of oxygen relative to the fuel in the exhaust gases. This can happen when the engine is idling or running at a low load.
  - A medium voltage (approximately 0.45 volts) generally corresponds to an ideal air-fuel mixture, with a sufficient amount of oxygen for complete combustion.
  - A higher voltage (approximately 0.6 to 0.9 volts) indicates an oxygen-lean mixture, meaning there is too much oxygen relative to the fuel in the exhaust gases. This can occur during acceleration or at high load, when the engine needs more air to burn the fuel efficiently.
- **How the Measurement Principle is Used**

The lambda sensor helps the engine management system adjust the air-fuel ratio in real-time to keep the engine as close as possible to the stoechiometric mixture. This helps reduce polluting emissions such as nitrogen oxides (NOx), hydrocarbons (HC), and carbon oxides (CO).

The oxygen content of the exhaust gases varies from zero in a rich mixture to approximately 10% in a lean mixture, as shown in Fig. 2.25.

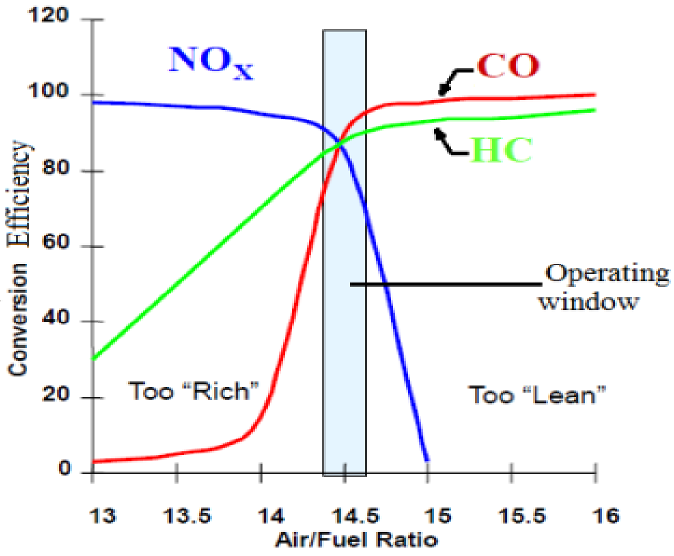


Figure II.25.Ratio of pollutant emissions in exhaust gases

9.4. Lambda Sensor Control

Lambda sensor failures can lead to decreased engine performance, increased emissions, and higher fuel consumption. Automotive diagnostic tools can analyze fault codes related to the lambda sensor to identify potential problems, such as defective sensors, damaged cables, or abnormal operating conditions.

Controlling the lambda sensor is an important step in diagnosing issues related to a vehicle's exhaust system and engine management system.

- **On-Board Diagnostic (OBD-II) Code Analysis**

  Modern vehicles are equipped with an on-board diagnostic system called OBD-II (On-Board Diagnostics II). By using an OBD-II compatible diagnostic tool, you can retrieve the error codes associated with the engine management system, including codes related to the lambda sensor. These codes can provide clues about any potential problems with the lambda sensor's operation.

Figure II.26.OBDII 16 SELF-TEST Connector

- **Using a Multimeter**

  A Multimeter can be used to measure the output voltage of the lambda sensor. By connecting the multimeter to the lambda sensor's terminals and observing the real-time voltage while the engine is running, you can evaluate whether the sensor is producing voltages within the expected range for the engine's operating conditions.

Figure II.27. Multimeter

- **Analyzing Signals on an Oscilloscope**

  For a more detailed evaluation of the lambda sensor's function, an oscilloscope can be used to visualize the voltage signal produced by the sensor over time. This can help identify performance issues, such as slow responses or incorrect signals.

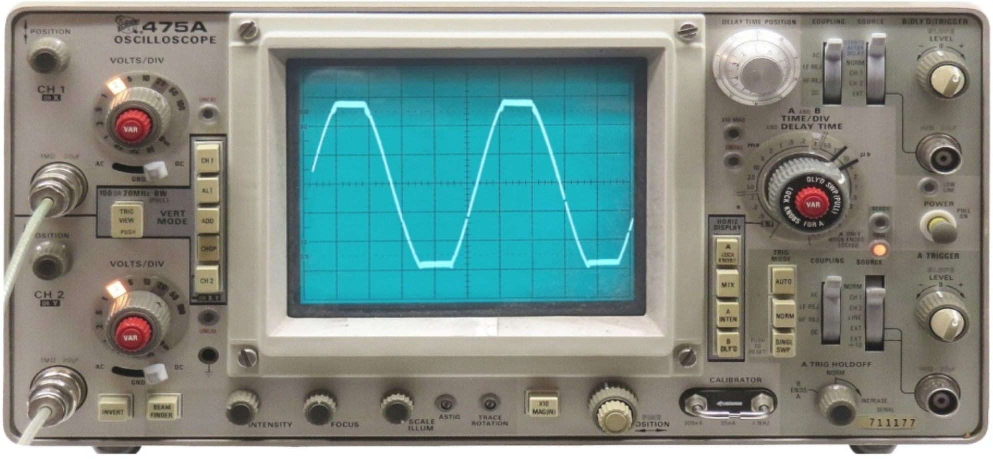


Figure II.28. Oscilloscope

- **isual Inspection and Cleaning**

  Sometimes, carbon deposits or other contaminants can accumulate on the lambda sensor, which can affect its performance. A visual inspection of the lambda sensor and cleaning it if necessary can help restore its efficiency.

- **Lambda Sensor Replacement**

  If previous tests indicate that the lambda sensor is faulty or defective, it's recommended to replace it with a new, high-quality lambda sensor that is suitable for the vehicle's make and model.

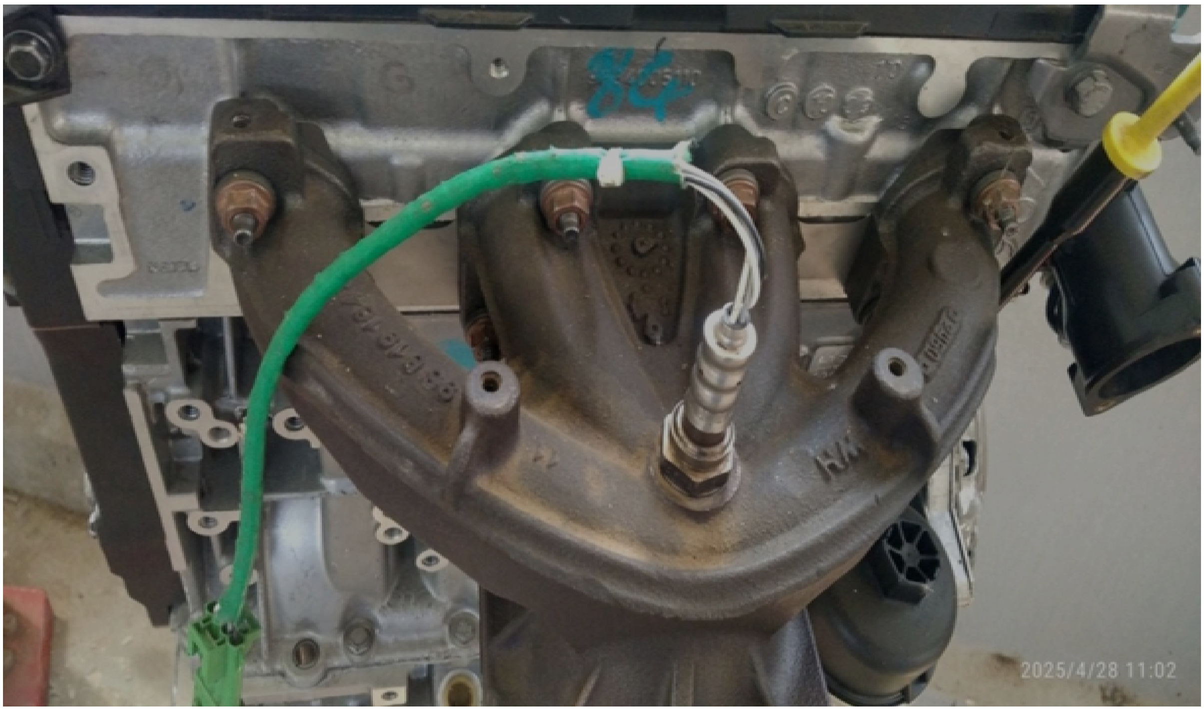


Figure II.29. Location of the lambda probe in a Renault engine

10. Knock Sensor

10.1. Definition

A knock sensor is a type of sensor used in cars to measure engine vibrations. Knocking is a muffled, rhythmic metallic noise you might hear when an engine is malfunctioning or under a heavy load.

The knock sensor is typically mounted on the engine block and uses a microphone or a piezoelectric sensor to detect engine vibrations. When the engine begins to knock, the sensor sends a signal to the car's on-board computer, which can then adjust the combustion in the engine to prevent damage to internal parts.

Figure II.30.Knock Sensor

The knock sensor can be especially important on turbocharged engines, where boost pressure can cause knocking. In these cases, the sensor can help prevent engine overheating, detonation, and internal damage.

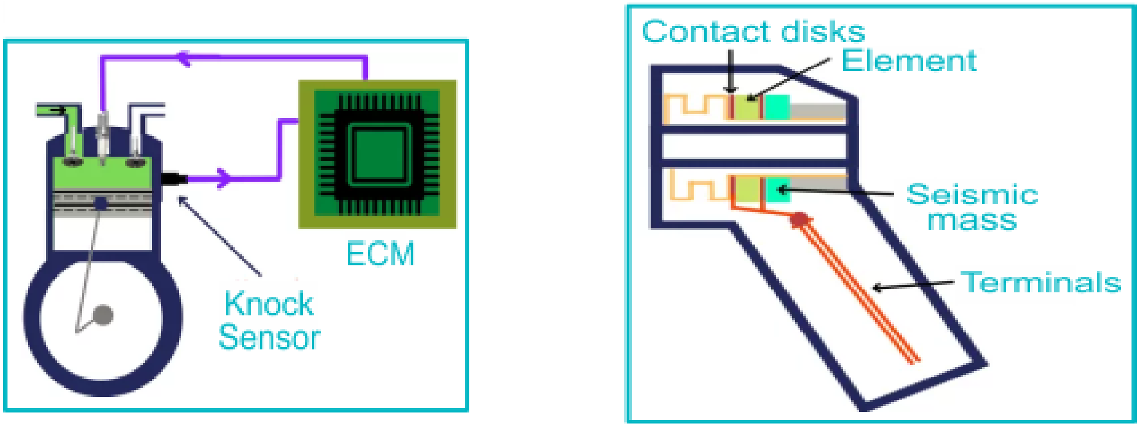


Figure II.31. Knock sensor principle

The knock sensor measures the vibrations of the engine block by piezoelectric effect. The signal is then processed at the computer level: The presence of knocking is linked to a fault in the ignition advance.

10.2. Principle of Detonation

Assuming an ideal fuel mixture and cylinder filling, if we start combustion in a closed chamber, the combustion of the first layer causes the pressure in the chamber to rise. An increase in pressure leads to an increase in temperature. The pressure in the chamber becomes so strong that it causes the entire remaining mass to ignite simultaneously, this phenomenon is called detonation.

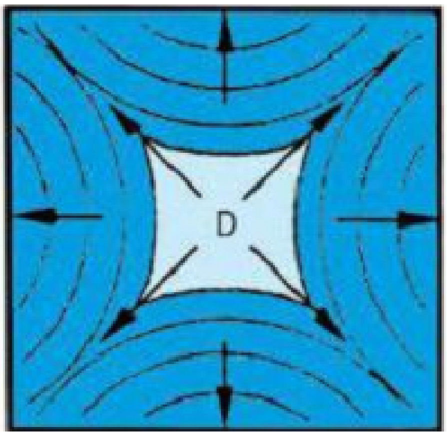


Figure II.32. Principle of detonation

Detonation can cause:

- a loss of power,
- abnormal engine heating,
- creep or melting of components in contact with the flame,
- fatigue of mechanical components.

10.3. Operating Principle

- When the engine is running normally, the sensor does not detect any abnormal vibrations and produces no signal. However, when the engine starts to knock, the sensor detects the vibrations and generates an electrical signal.
- The electrical signal produced by the knock sensor is sent to the car's on-board computer, which analyzes the signal to determine if the knocking is normal or abnormal. If the knocking is abnormal, the on-board computer can adjust the combustion in the engine to prevent damage to internal parts.

- The knock sensor's signals can also be used to adjust the amount of fuel injected into the engine, the ignition timing, and other engine operating parameters, this helps optimize engine performance while preventing internal damage.

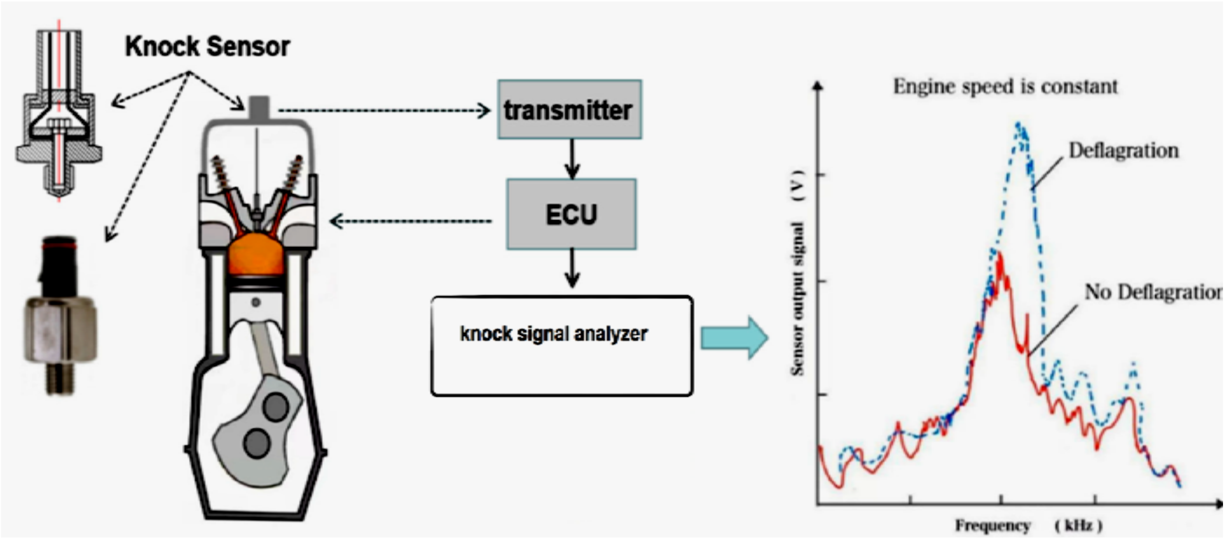


Figure II.33.Operation (with and without rattling)

A piezoelectric knock sensor is mounted on the engine block. On V6 engines, there are two knock sensors. These sensors detect knocking, which a vibrational phenomenon is caused by detonating combustion in the combustion chamber. Repeated knocking can destroy mechanical parts due to an abnormal rise in the temperature of the cylinder walls. This sensor delivers a voltage that corresponds to the engine's vibrations.

- After receiving this information, the engine control unit (ECU) reduces the ignition timing advance by 2° for the affected cylinder(s), with a maximum decrease of 12°.
- The timing advance will then be gradually re-incremented. In parallel with the timing adjustment, the ECU enriches the air/fuel mixture to avoid a significant rise in exhaust gas temperature, which could destroy the catalytic converter.
- When accelerating abruptly, the voltage delivered by the knock sensor should be between 0.1 and 1 volt; this is an alternating current (AC) voltage.

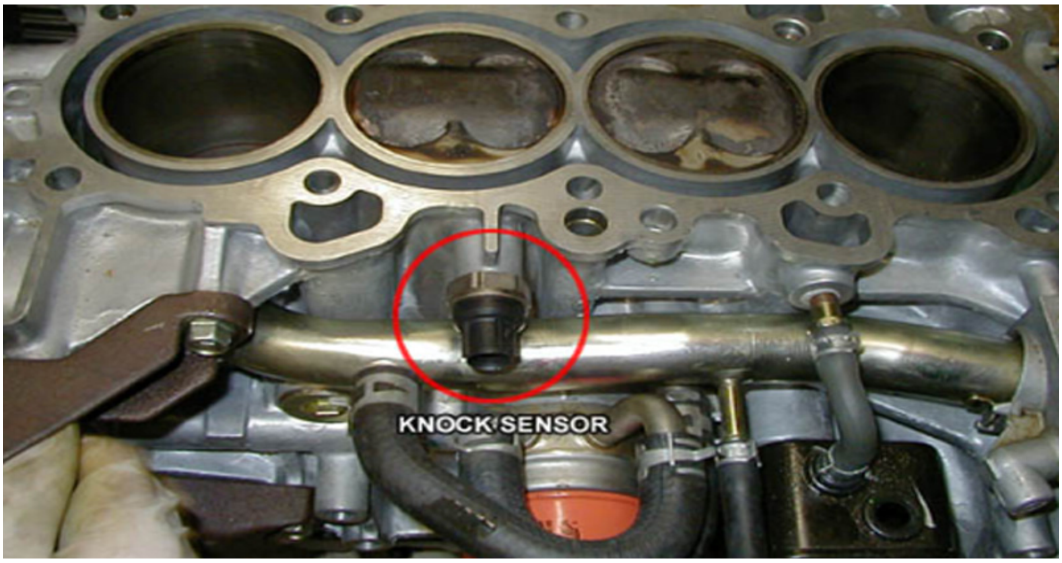


Figure II.34. Knock sensor location in a Renault engine

11. Throttle sensor

The throttle position sensor (TPS), also known as a throttle potentiometer, is an electronic device that measures the position of the throttle valve (or butterfly valve) and transmits this information to the engine control unit (ECU). This information is crucial for proper engine function because it helps determine the amount of air entering the engine and, consequently, the amount of fuel to inject.

Figure II.35.throttle position

The potentiometer is attached to the throttle body and informs the ECU of the throttle's angular position. This information is used to recognize the "foot lifted," "foot to the floor," and "transitional" positions. Based on this data, the ECU can identify the operating mode and apply the appropriate timing and injection strategies. Furthermore, it allows the ECU to calculate an injection time based on the throttle position, ensuring a backup mode in case of a pressure sensor failure.

Figure II.36.The throttle position sensor (potentiometer)

12. The ABS system Sensor

The anti-lock braking system (ABS) is an important safety system in modern automobiles, designed to prevent wheels from locking during emergency braking. ABS sensors are key components of the ABS system, detecting wheel movement and sending signals to the vehicle's electronic control unit (ECU) to adjust braking pressure.

Figure II.37.The ABS system sensor

In a car equipped with ABS, there are typically four ABS sensors, one for each wheel. The sensors are mounted near the wheels and are designed to measure the rotational speed of each wheel in real time. The sensors can be magnetic or based on electrical impulses and are often connected to a barrel ring that rotates with the wheel hub.

12.1. Operating Principle

- When a driver brakes suddenly, the ABS system measures the rotational speed of the wheels using ABS sensors. If one wheel slows down more quickly than the others, it means it's about to lock up, which could cause the car to lose control. The vehicle's ECU then uses this information to reduce braking pressure on the wheel that is locking up while maintaining braking pressure on the other wheels to keep the car stable and in control.
- ABS sensors in a car are important components of the anti-lock braking system (ABS). They measure the wheels' rotational speed and send signals to the vehicle's ECU to adjust braking pressure during emergency braking; this contributes to the vehicle's safety and stability.

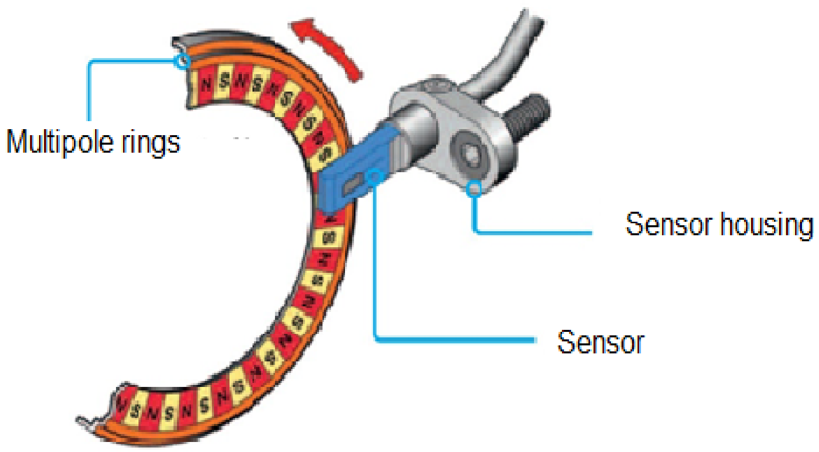


Figure II. 38. ABS sensor principle

12.2. ABS System Circuit

The ABS (Anti-lock Braking System) was originally designed to maintain better control over both the braking system and the vehicle's steering.

During emergency braking, the ABS regulates the pressure in the braking circuit by adjusting the maximum pressure level for each wheel. If a wheel locks up, the system releases the braking pressure in that specific wheel's circuit only.

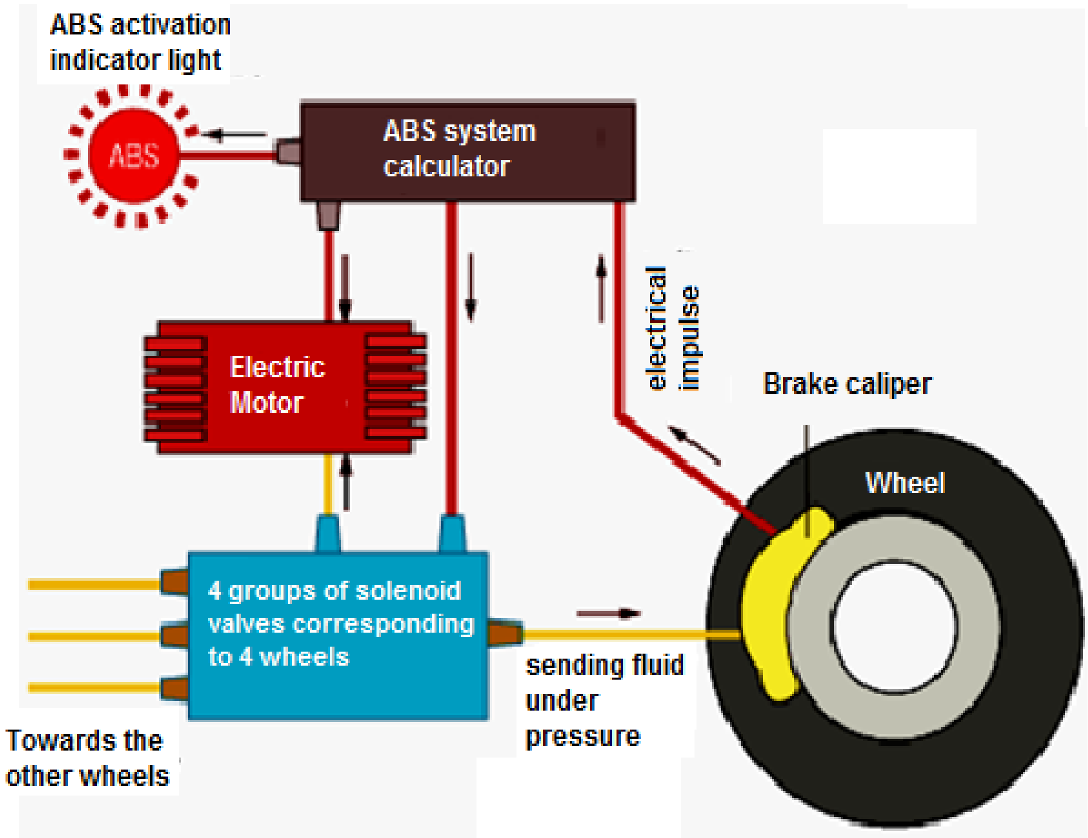


Figure II.39.ABS braking circuit

In a normal braking situation, the solenoid valves are open. When the ABS activates, it first closes a solenoid valve, which stops the flow of brake fluid. If the wheel continues to lock up, a second solenoid valve is closed, and so on. As the brake calipers are released, the wheels are freed. As soon as the wheel starts to regain speed, pressure is returned, also in stages, until the wheel reaches the same rotational speed as the others or until it begins to lock up again.

This process can occur up to 12 times per second, ensuring a more or less consistent braking (which explains why the driver feels vibrations in the brake pedal). ABS therefore requires an extremely sophisticated regulator; it must not only react very precisely to the information it receives but also account for the various inertias of the braking system and even the different diameter of a spare tire that may not be the same size.

13. Conclusion

Today, onboard sensors are the essential sensory organs of modern smart systems. As we have demonstrated throughout this chapter, these devices play a central role in the digital transformation of embedded systems, enabling the precise perception and measurement of various physical quantities.

A detailed analysis of the different sensor technologies—whether inertial, optical, thermal, or environmental—reveals a constant evolution toward:

- Better metrological precision
- Reduced energy consumption
- Easier integration

However, significant technological challenges remain, particularly in terms of:

- Robustness against extreme environmental conditions
- Long-term reliability
- Security of acquired data
- Interoperability in distributed architectures

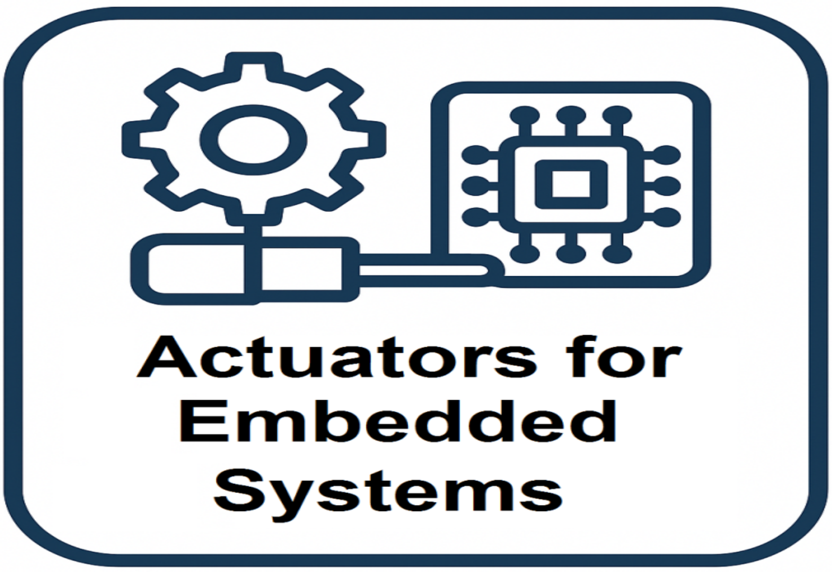
Future trends, marked by the emergence of smart sensors that integrate data preprocessing capabilities and the appearance of new measurement technologies, suggest promising prospects. The increasing integration of AI directly into sensors is notably paving the way for embedded systems that are more and more autonomous and high-performing.

Chapter III

Actuators for embedded systems

This chapter presents :

- ✓ *The role of actuators in an embedded system*
- ✓ *The different types of embedded actuators*
- ✓ *Signal management and synchronization*



1. Introduction

In a modern car, embedded systems use numerous actuators to control a variety of mechanical, electronic, and comfort functions. These actuators are managed by Electronic Control Units (ECUs) via on-board networks such as CAN (Controller Area Network) and LIN (Local Interconnect Network). Their seamless integration is vital for autonomous vehicles, where precision and reliability are absolutely critical.

2. Hydraulic actuators

Hydraulic actuators are used for movements requiring very high forces at low speeds. Using oil at pressures up to 400 bars, they can create cylinders with incredible force (up to 3,000,000 N, or 300 tons of force). Their response times are faster than with air (a few milliseconds) because oil is almost incompressible.

The oil is supplied by a hydraulic pump that is usually part of the machine. It's distributed through pipes to the receiving components. The oil that escapes during the operation of the actuators is fully recovered and returned to the pump after filtering and, if necessary, cooling.

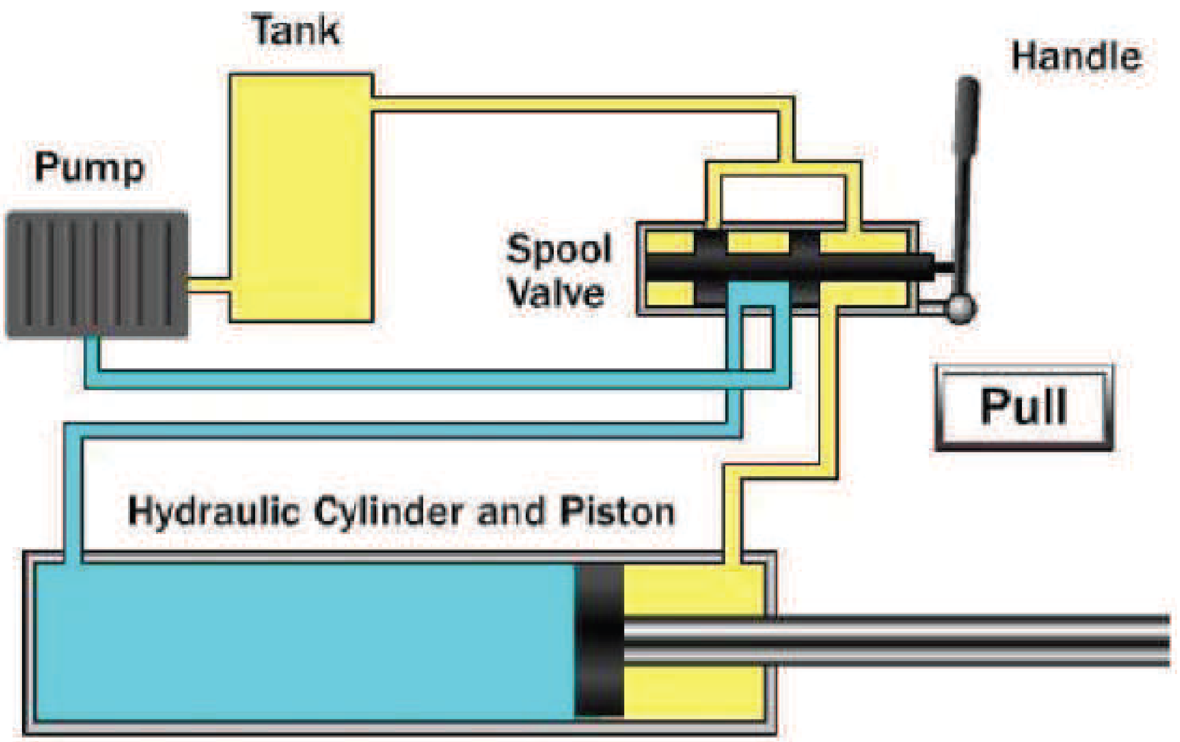


Figure III.1. Principle of a linear cylinder and its actuator

A hydraulic actuator for a vehicle is a device that uses the pressure of a hydraulic fluid, usually oil, to convert hydraulic energy into mechanical motion. This motion can be linear, as in a cylinder, or rotary, as in a hydraulic motor. Hydraulic actuators are used in various vehicle systems for applications such as power steering, brakes, suspension, and lifting heavy loads.

In modern vehicles, actuators play a key role in engine and transmission management, ensuring performance, energy efficiency, and compliance with environmental standards. These devices convert electronic signals into mechanical actions, allowing for precise control of different systems.

2.1. Architecture of Embedded Hydraulic Systems

Embedded hydraulic actuators are key components in modern automotive architectures, especially for critical functions like braking, steering, and suspension, with the advent of autonomous and electric vehicles, their integration into embedded systems is evolving toward more compact, intelligent, and connected solutions.

2.1.1. Hydraulic Pump

In the automotive industry, hydraulic pumps are essential for several systems, notably power steering and, in some cases, engine cooling. The power steering pump converts the engine's mechanical energy into hydraulic energy to make steering easier, especially at low speeds. The water pump, on the other hand, circulates coolant to prevent the engine from overheating.

Figure.III.2.Hydraulic Pump

Different types of pumps (gear, vane, and piston) use different mechanisms to create fluid flow and pressure.

2.1.2. Pilot-operated solenoid valves

A pilot-operated solenoid valve is a valve controlled by an electrical signal that regulates the flow of a fluid (liquid or gas) in a circuit; it is often used to regulate the turbo pressure in internal combustion engines.

Figure III.3. Pilot-operated solenoid valves

2.1.3. Pressure sensors

Pressure sensors in automobiles are devices that measure the pressure of various fluids and gases within the vehicle. They provide crucial information to the vehicle's computer, or ECU (Engine Control Unit), ensuring the proper functioning of the engine and the safety of the occupants. You can find them in several systems, including the braking system, the air intake system, the exhaust system, and the Tire Pressure Monitoring System (TPMS).

Figure III.4. Intake pressure sensors

2.1.4. Hydraulic ECU

The ECU (Electronic Control Unit), or engine control unit, is the electronic "brain" that manages the engine's functions and, in some cases, other vehicle systems. It doesn't directly manage hydraulic systems itself, but it communicates with hydraulic control units (such as those in ABS braking systems or power steering) to optimize their operation.

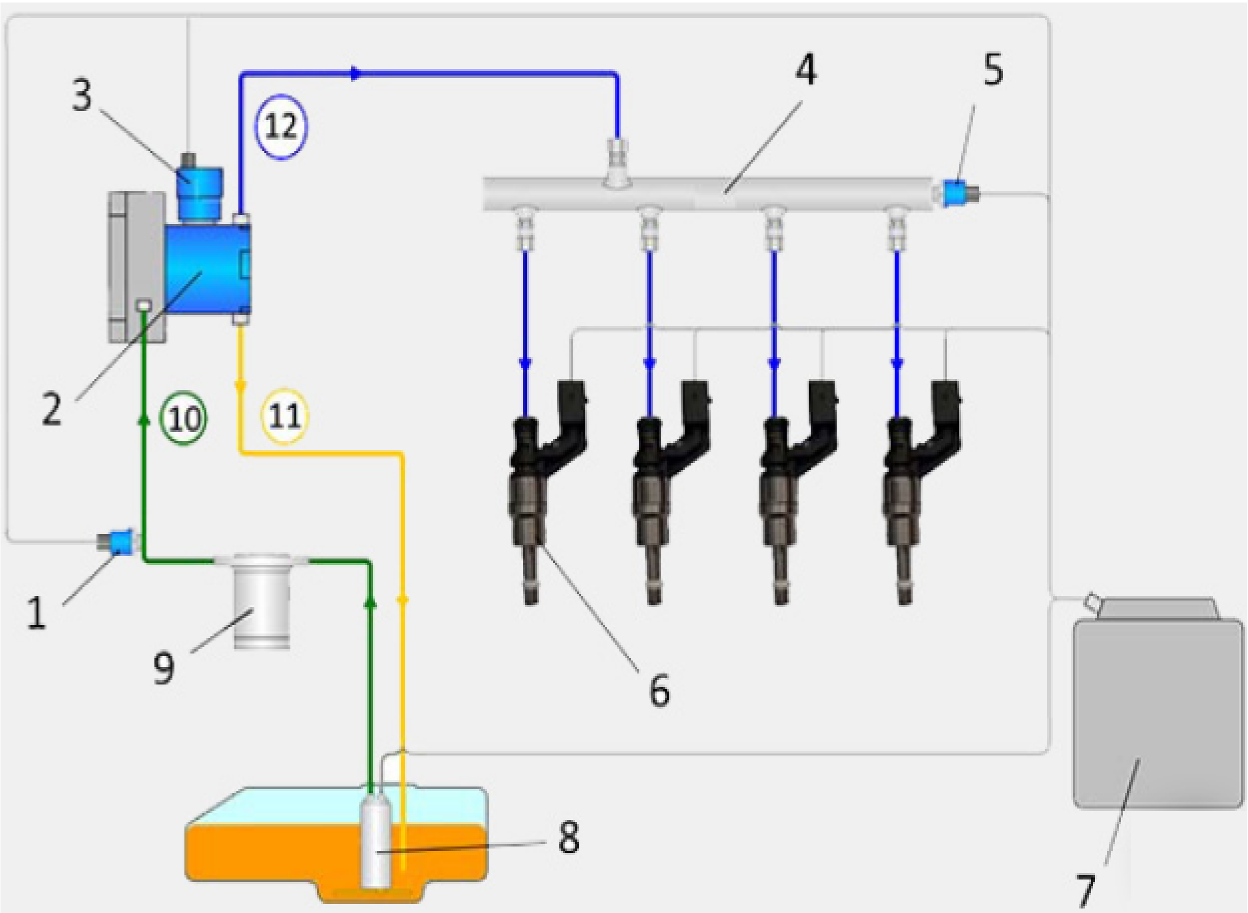
- ✓ The ECU receives information from various sensors (e.g., wheel speed, steering wheel angle).
- ✓ The ECU then sends signals to actuators, including those that control hydraulic systems.

Figure III.5. Hydraulic unit control ECU – Mercedes -

Figure.III.6. ECU ABS Brakes Hydraulic Module – HYUNDAY-

2.2. Actuators for Motorization

In automotive engineering, actuators are devices that convert a command into movement or physical action. They are essential for the operation of many systems in a vehicle, ranging from the engine to comfort systems (Injection and Fuel Supply, Emission Control and Turbo charging, Cooling and Thermal Management, etc.)



(1) low fuel pressure sensor, (2) high pressure fuel pump, (3) pressure control valve, (4) fuel rail, (5) high fuel pressure sensor, (6) injectors, (7) engine control unit, (8) electric fuel pump, (9) fuel filter, (10) low fuel pressure system, (11) fuel return system, (12) high fuel pressure system

Figure III.7.Example of a fuel system in the vehicle

2.2.1. The fuel pump

The fuel pump is an electric motor or diesel pump (on diesel engine cars). The fuel pump ensures that fuel is delivered from the tank to the engine. It is used to supply the vehicle's injection system. This part is located in the fuel tank.

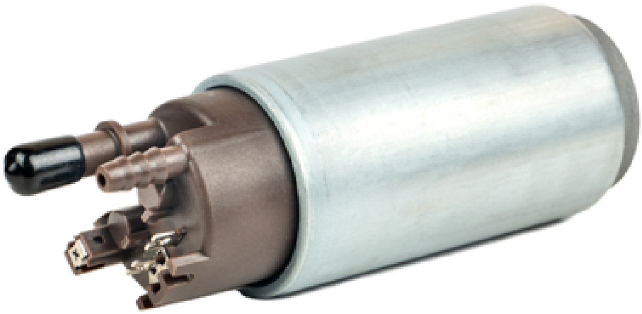


Figure III.8.The fuel Pump

Most recent cars use an electric pump submerged in the fuel tank.

The main components are:

- ✓ **Electric motor**: Powers the pump.
- ✓ **Impeller or turbine**: Sucks in and pushes out the fuel.
- ✓ **Check valve**: Prevents fuel from returning to the tank.
- ✓ **Fuel filter**: Protects the pump from impurities.
- ✓ **Pressure regulator**: Maintains constant pressure (around 3 to 5 bars for injection).

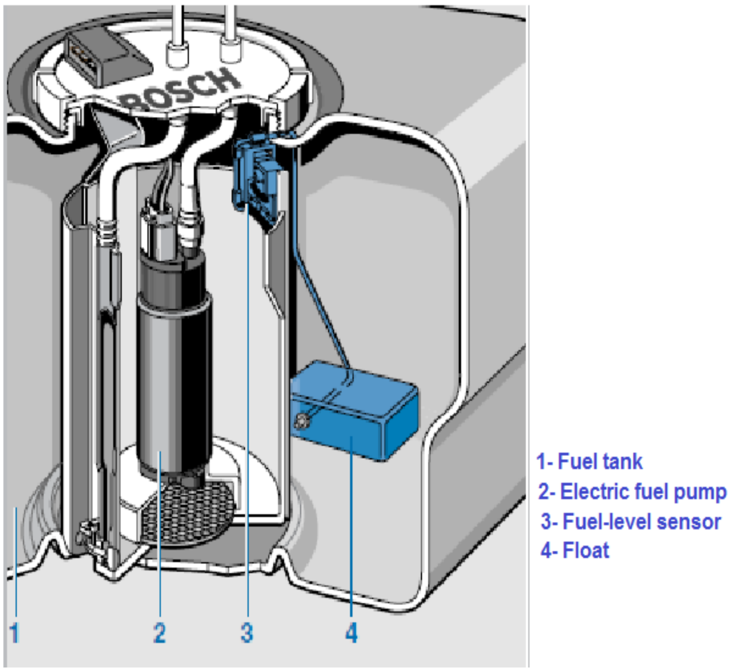


Figure III.9.fuel pump components

Steps of Operation:

- ✓ **Ignition on**: The pump is activated for a few seconds to prime the system.
- ✓ **Suction**: Fuel is drawn from the tank.
- ✓ **Delivery**: The pump sends the pressurized fuel to the engine through the fuel lines.
- ✓ **Regulation**: The regulator adjusts excess pressure (the surplus returns to the tank).
- ✓ **Shutdown**: The pump turns off if the engine isn't running (safety feature).

Role in the Injection System

- ✓ Supplies the **injectors** with pressurized fuel.
- ✓ Enables fine fuel atomization for optimal combustion.
- ✓ Works in coordination with the **engine control unit** (which adjusts the flow based on needs).

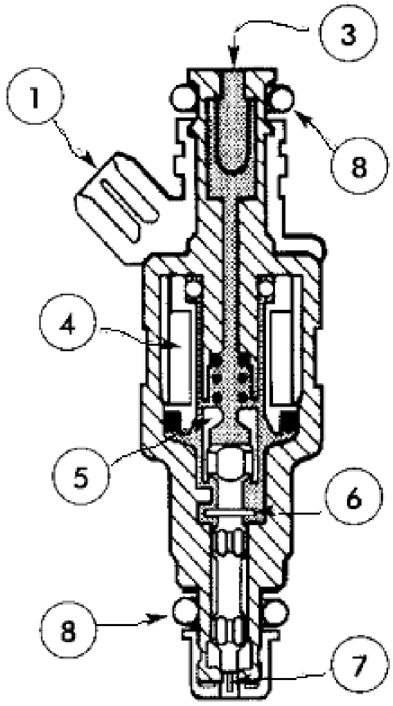
Common Failures

- ✓ **Pump doesn't start** (blown fuse, faulty relay).
- ✓ **Abnormal noise** (pumps wear or clogged filter).
- ✓ **Loss of pressure** (leak, faulty valve).
- ✓ **Excessive fuel consumption** (worn-out pump struggling to maintain pressure).

2.2.2. Les injecteurs

Injectors are key components of modern injection systems, responsible for the precise delivery of fuel into the engine.

Figure III.10. Electromagnetic injector



1- Electrical connection
2- Fuel return
3- Arrived fuel
4- Coil
5- Magnetic core
6- Needle
7- Injection nipple
8- O-ring

Figure III.11.The components of an injector

- **Role of Injectors**
  - ✓ Atomize the fuel into a fine mist in either:
    - The intake manifold (indirect injection)
    - The combustion chamber (direct injection)
  - ✓ Precisely meter the amount of fuel based on the engine's needs (controlled by the ECU).
  - ✓ Optimize combustion to reduce fuel consumption and polluting emissions.
- **How They Work**

Electrical pulses from the electronic injection control unit create a magnetic field in the electromagnet's winding; the core is attracted, and the injector's needle lifts from its seat. Fuel is sprayed upstream from the valve seat.

The quantity of fuel injected is a function of the injectors' opening time (known as injection time).

The operation can be summarized in three steps:

- ✓ Controlled by an electrical pulse from the ECU.
- ✓ A solenoid activates a needle to release the fuel.
- ✓ Used on modern gasoline and diesel engines.

2.2.3. Moteur pas à pas

A stepping motor is a type of brushless electric motor that divides a full rotation into a number of equal steps. It can be precisely controlled to move and stop at any one of these steps, hence its name.

- **Principle of Operation**

  Unlike traditional electric motors that rotate continuously, a stepping motor moves one step at a time. A controller sends electrical pulses to the motor's coils, which generate magnetic fields that attract and repel the rotor's permanent magnet, causing it to pivot by a fixed angle (the step). The sequence and frequency of the pulses determine the direction and speed of the rotation.

Figure III.12. Stepper motor

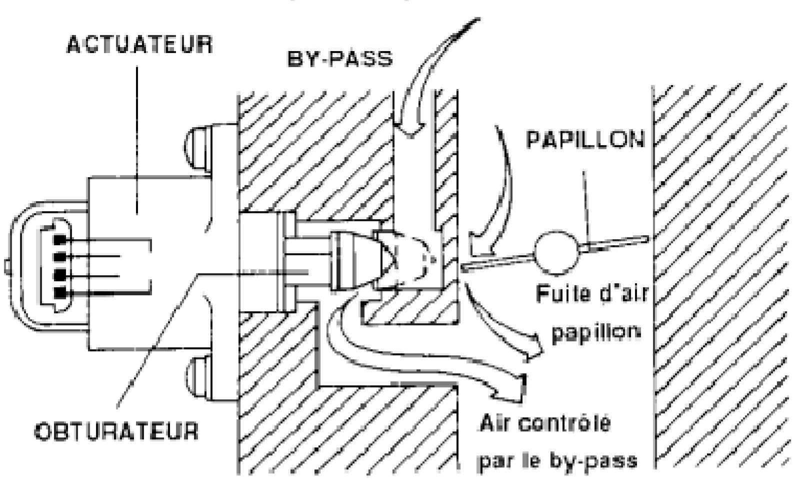


Figure III.13.Stepper motor working principle

- **Applications of the Stepping Motor in Vehicles**

In a car, stepping motors are used in several applications that require precise control and exact positioning.

- **Idle Speed Regulator**

The most common role of a stepping motor is to act as an idle speed regulator. It adjusts the airflow entering the engine when the vehicle is idling to keep it stable and prevent it from stalling. The engine control unit (ECU) controls it to increase air intake when the engine is under load (for example, when turning on the air conditioning or headlights), thus preventing the engine speed from dropping too low.

- **Other Applications**

They are also found in other car systems, including:

- ✓ Electric seat adjustment for precise positioning
- ✓ Headlight beam control to adjust direction and intensity
- ✓ Windshield wiper systems for variable intermittent operation
- ✓ Fuel injection and automatic transmission valve control.

2.2.4. Actuator in the Ignition Circuit:

2.2.4.1. Ignition Coil

- **Classic Ignition Coil**

Electric, solar-powered, and alternate fuel vehicles are the wave of the future, but for now most cars run on gasoline, which they burn in an internal combustion engine to convert into motion. For combustion to take place, a spark is needed to ignite the fuel mixture in the engine. The vehicle's ignition system is designed so that a 12-volt battery can generate the very high voltage required to create such a discharge. The heart of this system is a device called an ignition coil.

Figure III.14. Ignition coil (old model)

Several components are involved in the ignition of the air-fuel mixture. The spark plug, ignition cables and the ignition coil are all of significant importance. The ignition coil is found at the beginning of the ignition process, as it generates the high voltage which produces the spark discharge at the spark plug.

In the classic type shown here, a mechanical distributor ensures that this voltage reaches the individual cylinders and spark plugs in turn and at the right time.

In this set up, the ignition voltage is fed through the distributor cap and the ignition cable to the spark plug connector. From here, it reaches the end of the centre electrode and crosses the gap to the ground electrode as a spark.

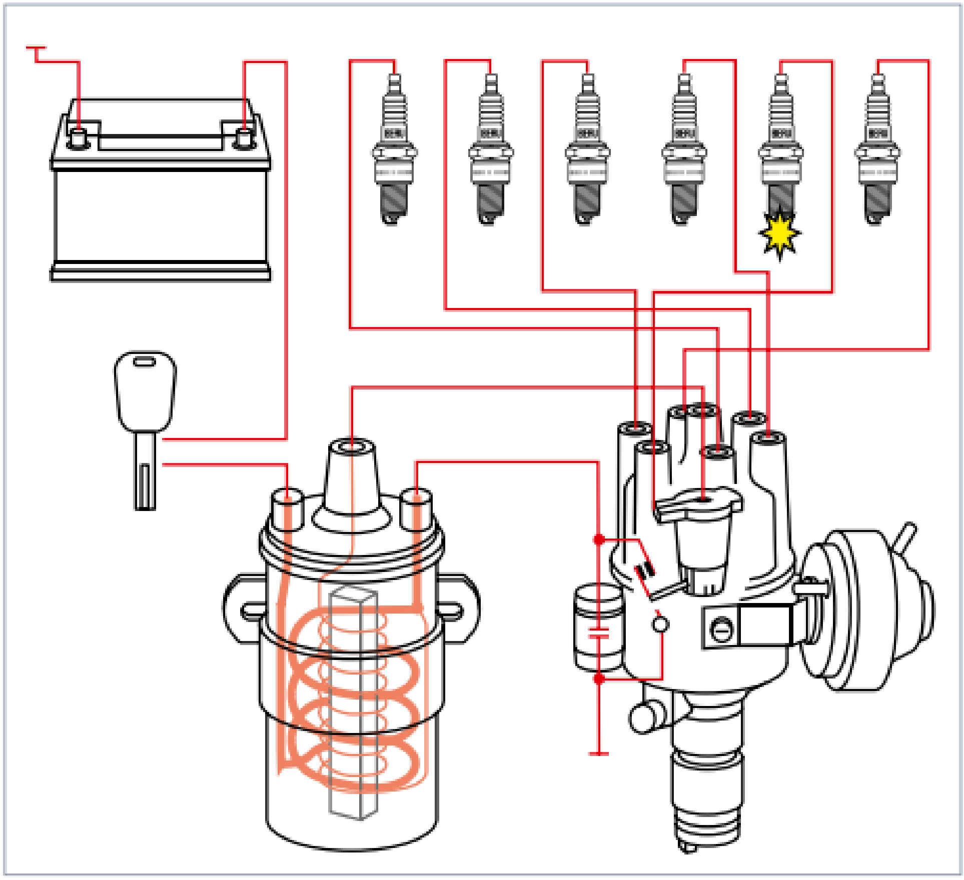


Figure III.15.The ignition coil’s function within the ignition process

- **Breaker-Point Ignition**

In this system, high voltage is produced centrally by a single ignition coil and mechanically distributed to each spark plug by an ignition distributor. This type of voltage distribution no longer plays any role in modern engine management systems.

- **Electronic Ignition Coils for Distributor Systems**

The electronic ignition system replaced the old breaker-point systems, offering better precision, greater reliability, and a higher voltage, which improves combustion and engine performance.

Double-spark ignition coils simultaneously produce a spark for two spark plugs mounted on two different cylinders. These results in voltage being distributed so that the air-fuel mixture in one cylinder at the end of the compression stroke (ignition point) is ignited (the main spark—a more powerful ignition spark), while the ignition spark for the other cylinder occurs at the same time during the exhaust phase (the auxiliary spark—a weaker energy spark).

Figure III.16.New model ignition coil (for gasoline injection engine)

2.2.4.2. Spark Plugs

The spark plug plays an essential role in a gasoline engine. It is responsible for igniting the air/fuel mixture. The quality of this ignition has a direct impact on driving quality and the environment. This includes easier starting, more linear acceleration, better engine performance and efficiency, and reduced pollutant emissions.

Figure III.17.Spark plug

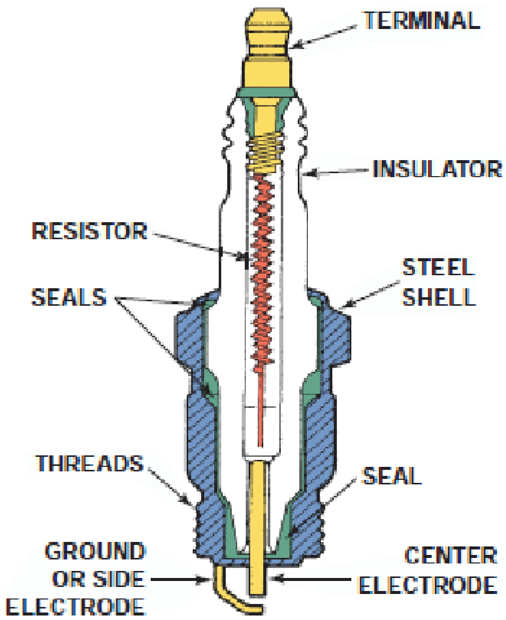


Figure III.18.The components of a spark plug

- If we consider that a spark plug must ignite the air/fuel mixture 500 to 3,500 times per minute, it becomes clear that the function of a spark plug is paramount from both a technical and environmental standpoint.
- The ignition voltage is transmitted by a distributor head and a high-voltage cable connected to the spark plug. The current then reaches the end of the center electrode, and when the voltage is sufficient, the energy is discharged as a spark, which forms between the ground electrode and the center electrode.

- In more modern systems, a so-called "pencil" ignition coil is often mounted directly on each spark plug. In this case, neither mechanical ignition nor high-voltage wire sets are necessary.

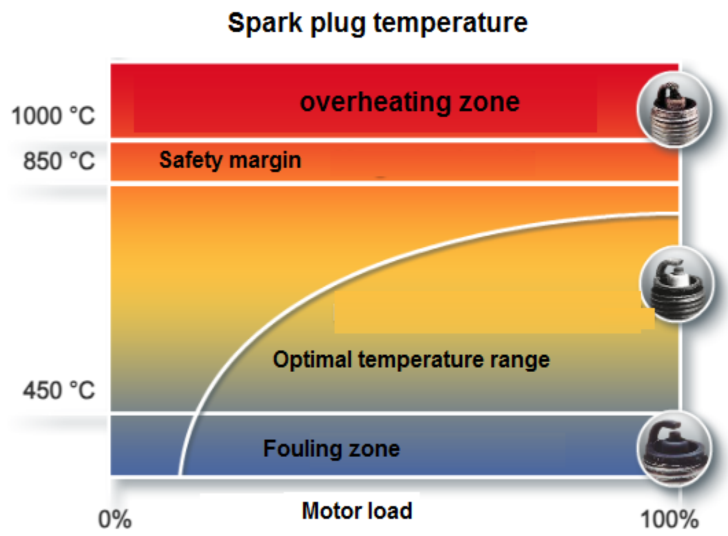


Figure III.19.Spark plug temperature

- For a spark plug to work efficiently, its firing end must be kept within a specific temperature range.
- The minimum threshold of this thermal range is 450°C, also known as the self-cleaning temperature of the firing end. Above this threshold, carbon residues (also called "fouling") that accumulate on the spark plug's insulator are burned off.
- Carbon deposits are a consequence of the combustion process and accumulate on the surfaces of the combustion chamber. If the spark plug's temperature is below 450°C, conductive carbon particles build up on the insulator and create a deposit. If this fouling bridges the gap between the shell and the center electrode, the electrical circuit is closed, and the spark plug is grounded. The spark between the electrodes will then fail to occur.
- Conversely, a temperature of the firing end above 800°C can overheat the electrodes to the point that they become incandescent. This can ignite the air-fuel mixture before the spark occurs. This process can lead to uncontrolled ignition, resulting in abnormal combustion and potentially causing irreversible damage to the engine.

2.3. Actuators for the Transmission

In automotive transmissions, actuators are devices that convert control signals into physical actions, such as shifting gears or controlling the clutch. These can be electric, hydraulic, or electromechanical. Actuators play a crucial role in the proper functioning of transmissions, whether they are manual, automatic, or hybrid (Clutch and Gearbox, All-Wheel Drive and Differentials, Hybridization and Electric Vehicles, etc.).

- Gear shift actuators (or gear selector actuators) are key components in automated, robotic, and dual-clutch transmissions (DCTs). They replace the mechanical action of a gear lever by electronically controlling gear changes.

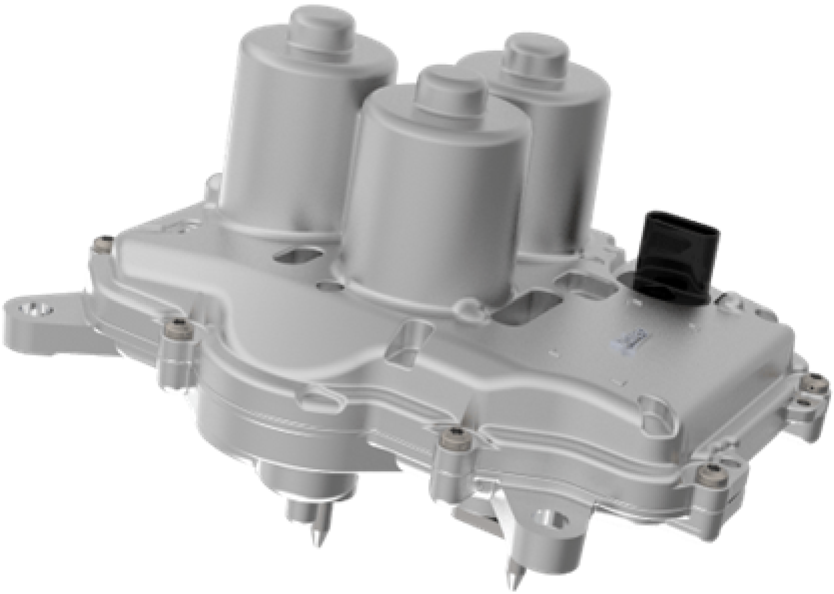


Figure III.20.Gearshift actuators of a vehicle

- A clutch actuator is a key component in transmission systems, especially in vehicles with an automated manual or automatic clutch gearbox. Its role is to engage and disengage the clutch automatically, without the driver having to press a clutch pedal. A hydraulic clutch actuator uses a pressurized fluid, similar to a traditional clutch system, but with an electronically controlled pump and cylinder. Examples include the Senso Drive gearbox (Citroën) and some BMW models.

Figure III.21. Car Transmission Clutch Actuator

3. Air Bag Actuator

Airbag actuators are essential components in the passive safety systems of modern automobiles. They are designed to quickly deploy airbags in the event of an accident to protect vehicle occupants from serious injuries.

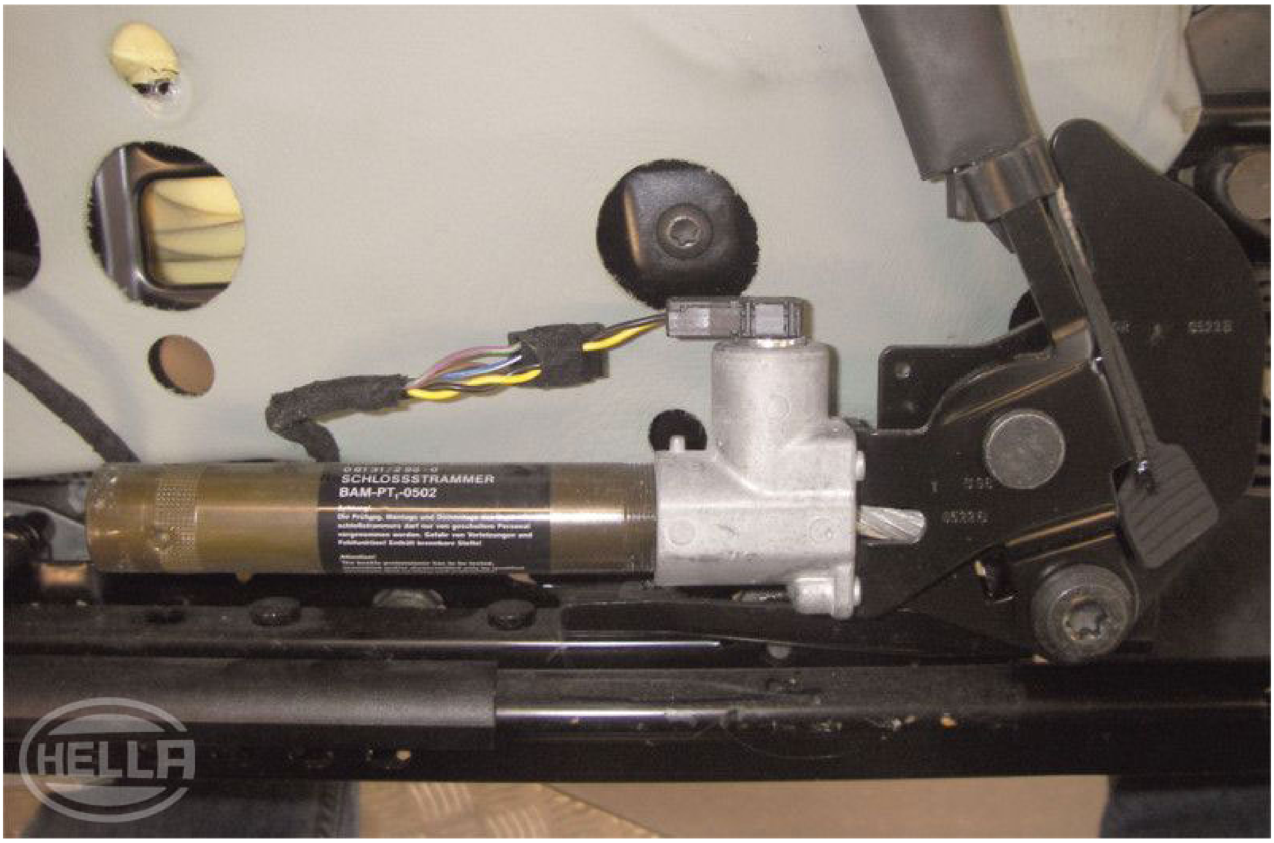


Figure III.22. Actuator for car airbags

Airbag actuators play a crucial role in protecting vehicle occupants in the event of an accident. By rapidly deploying the airbag at the moment of impact, they help reduce severe head, neck, and torso injuries by absorbing some of the kinetic energy generated by the collision.

3.1. Types of Airbag Actuators

There are different types of airbag actuators, primarily distinguished by their gas generation method:

3.1.1. Pyrotechnic actuators

These actuators use an explosive charge to trigger the release of the gas that inflates the airbag. They are the most commonly used type in automotive airbag systems.

Figure III.23.Pyrotechnic actuator for car airbags

3.1.2. Pneumatic actuators

Some airbag systems use pneumatic actuators that rely on compressed air or an inert gas to inflate the airbag. However, these systems are less common due to their higher complexity and cost.

Figure III.24.Pneumatic Actuator for Car Airbags (Ford F150 2015)

4. Air Conditioning System

Air Conditioning System Actuators are essential components of modern automotive air conditioning systems; they are responsible for regulating and controlling various elements of the AC system, such as temperature, airflow direction, and air distribution within the cabin.

Figure III.25.Air conditioning system actuator

Air conditioning system actuators are used in many systems and components of a vehicle's AC to ensure efficient and comfortable operation. Their primary applications are:

- **Temperature Control**: Hot/cold air mix actuators and air distribution flap actuators are used to control the cabin temperature by adjusting airflow and the mix of hot and cold air.
- **Air Distribution**: Air distribution flap actuators direct airflow to different areas of the cabin based on the driver's and passengers' preferences.
- **Air Recirculation**: Air recirculation actuators allow you to choose between recirculating air from inside the cabin or drawing fresh air from outside the vehicle, depending on driving conditions and occupant preferences.

4.1. Conditioning System Actuators

Air conditioning system actuators operate using various mechanisms to adjust the AC system's parameters, the most commonly used actuators in automobiles include:

4.1.1. Air Distribution Flap Actuators

These actuators control the opening and closing of flaps in the air distribution system to direct air toward different areas of the cabin, such as the dashboard, the foot wells, or the windshield.

Figure III.26.Air distribution flap actuator of an air conditioning system

4.1.2. Hot/Cold Air Mix Actuators

These actuators control the blend of hot air from the heating system and cold air from the air conditioning system. Their function is to maintain a comfortable temperature inside the vehicle's cabin.

Figure III.27.Hot/cold air mixing actuator of an air conditioning system

4.1.3. Air recirculation actuators

Control the opening and closing of the air recirculation system. This allows the system to either recirculation air from inside the cabin or draw in fresh air from outside the vehicle.

Figure III.28.Air recirculation Actuators

The air recycling or recirculation micro motor is a small electric motor that operates a flap to open or close the air passage in automotive ventilation systems.

4.2. Operation of the air conditioning system in the vehicle

A car's air conditioning system works by absorbing heat from the cabin and releasing it outside the vehicle, creating a cool and comfortable interior environment. Here are the main components and how they function:

- **Compressor**

  The compressor pressurizes the refrigerant gas, increasing its pressure and temperature.

- **Condenser**

  The high-pressure, high-temperature refrigerant is sent to the condenser, where it releases heat to the outside of the vehicle and condenses into a liquid.

- **Expansion Valve**

  The expansion valve lowers the pressure and temperature of the liquid refrigerant before it enters the evaporator.

- **Evaporator**

  The evaporator absorbs heat from the cabin air, causing the liquid refrigerant to evaporate into a gas. This cools the air, which is then sent into the cabin.

- **Blower Fan**

  The fan circulates the cooled air through the vents to cool the cabin.

4.3. Types of Air Conditioning System Actuators

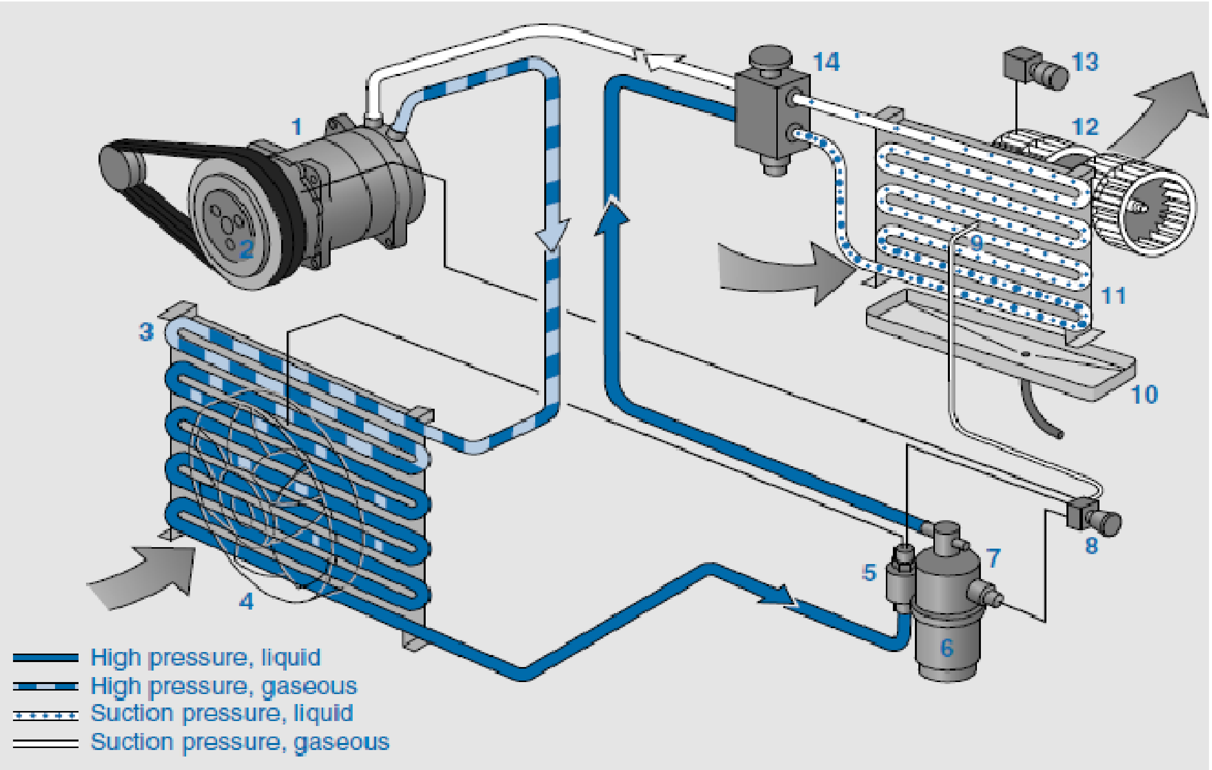
Air conditioning system actuators can be classified based on their control method and actuation mechanism:

4.3.1. Electric Actuators

These actuators use electric motors to perform the necessary movements for adjusting the components of the air conditioning system. They are widely used due to their precision and ease of control.

4.3.2. Pneumatic Actuators

Some air conditioning systems use pneumatic actuators, which rely on compressed air to operate the system's flaps and valves. These actuators are less common and have often been replaced by electric actuators in modern vehicles.



1- Compressor **2-** Solenoid clutch (for switching the compressor on/ off)
3- Condenser **4-** Auxiliary fan **5-** High-pressure switch
6- Fluid reservoir with desiccant insert **7-** Low-pressure switch
8- Thermostatic switch or on/off control (for compressor on/off)
9- Temperature sensor **10-** Condensate drip pan **11-** Evaporator **12-** Evaporator fan
13- Fan switch **14-** Expansion valve

Figure III.29.Air conditioning system

5. Braking system

The braking system is one of the most critical safety components in automobiles. The automotive braking system works by converting the vehicle's kinetic energy into heat through friction between the brake pads and the brake discs (or drums).

The operation of a vehicle's braking system is to convert an input force, typically provided by the driver via the brake pedal, into the actual braking force needed to slow or stop the vehicle.

5.1. Main Types of Actuators in Automotive Braking Systems

5.1.1. Brake Calipers

Brake calipers are hydraulic actuators used in disc brake systems. They contain pistons that are operated by the hydraulic pressure of the brake fluid. When the driver presses the brake pedal, hydraulic pressure is applied to the pistons, forcing the brake pads to clamp down on the brake discs, this creates friction that slows or stops the vehicle.

5.1.2. Wheel Cylinders

Wheel cylinders are actuators used in drum brake systems. They are also actuated by the hydraulic pressure of the brake fluid, but they exert force against the brake shoes. These shoes then press against the inner surface of the brake drum, slowing the vehicle.

5.1.3. Brake Boosters

Brake boosters (or braking assistance) are actuators that provide mechanical or hydraulic assistance to the driver when they press the brake pedal. They amplify the braking force applied by the driver, allowing for more effective braking with less effort from the driver.

5.2. Actuators in the Anti-lock Braking System (ABS)

In anti-lock braking systems (ABS), special actuators are used to control the hydraulic pressure applied to the brakes to prevent the wheels from locking up during braking. These actuators are typically electronically controlled solenoid valves that rapidly open and close hydraulic circuits. This action modulates the braking pressure on each wheel individually, ensuring better vehicle stability and control during emergency braking.

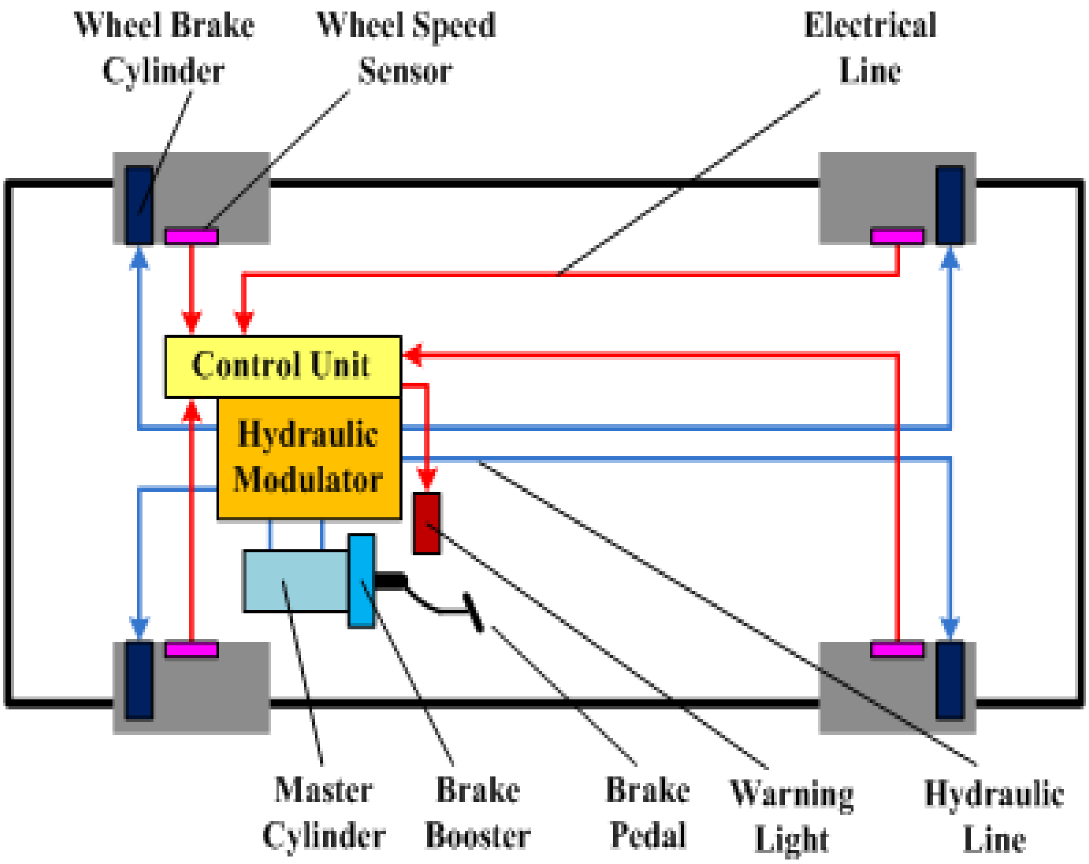


Figure III.30.Schematic of an anti-lock braking system (ABS)

Antilock Braking Systems (ABS) prevent wheel lockup by modulating the braking pressure. These systems play a significant role in improving the safety of modern vehicles. Braking hard, particularly on ice or wet roads can cause one or more wheels to lock and skid over the surface. This can result in longer stopping distances or even a loss of steer ability. ABS systems monitor the wheel speed in real-time and automatically regulate the brake pressure to prevent wheel lockup and improve the driver's control of the vehicle. They are now often paired with other systems such as Electronic Brake-force Distribution (EBD), Electronic Stability Control (ESC), and Traction Control to further increase vehicle control and driver safety.

The main components of these systems include regular brake parts (such as the brake pedal, hydraulic cylinders, and lines), wheel speed sensors, and a hydraulic modulator operated by an electronic control unit. The architecture of the ABS system (including the hydraulic modulator) is illustrated in the figure below.

The anti-lock braking system (ABS) prevents the wheels from locking during sudden braking, which allows you to:

- ✓ Maintain directional control of the vehicle.

- ✓ Reduce the braking distance on certain surfaces.

The ABS system is composed of:

- ✓ Wheel speed sensors
- ✓ An electronic control unit (ECU)
- ✓ Hydraulic actuators

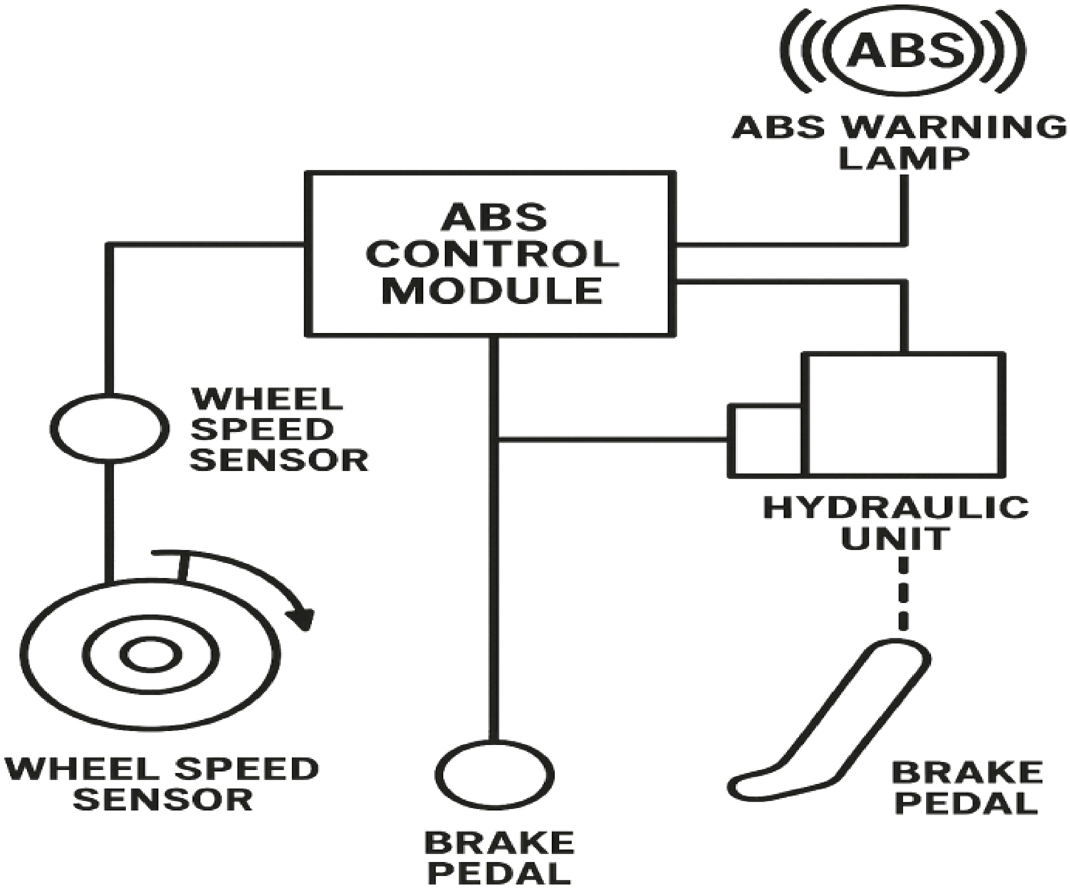


Figure III.31.The anti-lock braking system (ABS)

5.3. Types of Actuators in ABS

5.3.1. Solenoid valves

Are electrically controlled by the ECU and manage the flow of brake fluid to the calipers, this prevents wheel lock-up during emergency braking and improves vehicle stability.

There are two types of valves per wheel:

- **Inlet Valve** (Controls the pressure increase)
- **Outlet Valve** (Reduces the pressure)

Figure III.32.ABS solenoid valve

5.3.2. Recirculation Pump

The recirculation pump for the ABS system, also known as the ABS pump, is an essential component of your vehicle's anti-lock braking system. Its main role is to maintain constant pressure in the brake circuit when the ABS is active. This prevents the wheels from locking up during sudden braking, thus ensuring better vehicle control.

- ✓ It restores pressure to the circuit after a pressure release.
- ✓ It works with an electric motor.
- ✓ It prevents pressure loss in the brake pedal.

Figure III.33. Recirculation Pump

5.3.3. Electric Motor / Pump Motor

The electric motor (or ABS pump motor) is essential for maintaining stable hydraulic pressure, which allows the ABS to finely modulate braking and prevent the wheels from locking up.

- ✓ It activates the recirculation pump.
- ✓ It receives commands from the ECU based on wheel speed.

Figure III.34.Electric motor (pump motor)

6. Conclusion

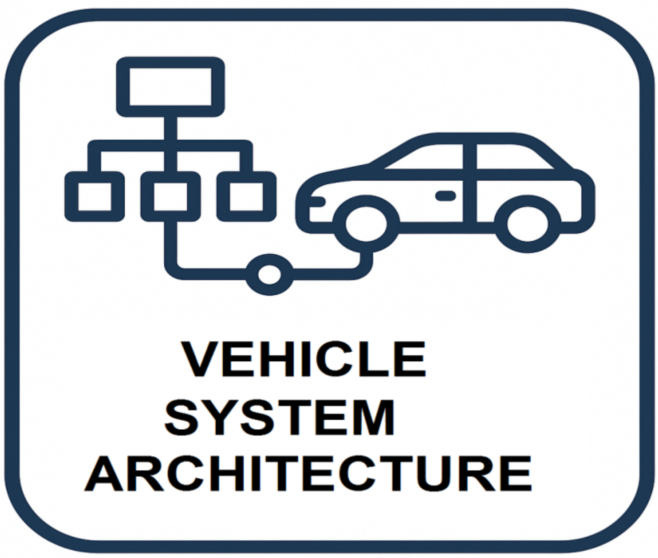
Actuators play a fundamental role in embedded systems, serving as the essential interface between electronic commands and mechanical actions. Throughout this chapter, we have explored the various types of actuators (electric, pneumatic, hydraulic, and piezoelectric, etc.), their operating principles, and their specific applications in embedded environments, along with technological advances, particularly in real-time control systems. Howe ver. challenges persist, such as integration into increasingly complex embedded architectures, managing thermal and mechanical constraints, and optimizing energy consumption. Future innovations, like bio-mimetic actuators or self-adaptive systems, open up promising prospects for even more high-performing and autonomous applications.

Chapter IV

Vehicle System Architecture

This chapter aims to introduce the concepts of electronic and software architecture:

- *Understand the role of ECUs*
- *Understand vehicle communication protocols (CAN)*
- *Identify the main subsystems (Sensor/Actuator Networks)*



1. Introduction

The automotive industry is undergoing a major transformation, shifting from traditional mechanics to an advanced integration of electronics, software, and communication networks. This evolution has given rise to increasingly complex vehicle architectures, designed to meet the demands of performance, safety, connectivity, and energy efficiency.

The architecture of a modern vehicle system is based on a hierarchical and interconnected structure, including electronic control units (ECUs), embedded networks (CAN, LIN, Ethernet), sensors and actuators, as well as human-machine interfaces (HMIs). These components must work in perfect synergy to ensure critical functions such as engine management, active and passive safety, infotainment, and, increasingly, autonomous driving.

This chapter explores the fundamental principles of vehicle systems architecture, analyzing its different layers (hardware, software, and network), its challenges (scalability, cyber-security, modularity), and future trends (centralization of ECUs, embedded artificial intelligence). Understanding this architecture is essential for grasping the technological innovations that are shaping the car of tomorrow.

2. Electronic Calculator in Vehicle

In modern vehicle electronics architecture, the electronic control unit, also known as an **ECU** (Electronic Control Unit), is a vital component. It plays a central role in managing and controlling various vehicle subsystems.

An automotive ECU functions by receiving data from sensors, processing this information, and then sending commands to **actuators**. It's essentially a network of specialized computers, each dedicated to a specific function such as engine control, transmission, or braking, These ECUs work together to optimize performance, safety, and fuel consumption.

Figure IV.1. The Electronic Calculator

2.1. How the ECU Works

An electronic control unit (ECU) in a car is a specialized microprocessor that receives inputs from various sensors, analyzes this information, and makes decisions based on predefined parameters and integrated control algorithms.

Key Components and Their Functions

- **Inputs**

  Sensors in different vehicle subsystems provide data to the ECU, such as vehicle speed, engine temperature, throttle position, and more.

- **Processing**

  The ECU processes this data in real time using embedded software. It compares the sensor values with predefined thresholds and runs control algorithms to determine the necessary actions.

- **Outputs**

  The ECU sends output signals to the vehicle's actuators, like fuel injectors, engine control valves, and transmission actuators, to adjust and control their operation.

An ECU is a casing with electrical pins that act as numerous input and output ports, allowing it to manage the vehicle's instruments. Inside, a programmable circuit board holds the system's software, primarily coded in C++ or Java.

Because they can make decisions based on input from sensors, ECUs are often referred to as "intelligent" systems. For example, an engine control unit (ECU) ensures the engine runs correctly by adjusting its needs in real time. It receives electrical signals from sensors (like temperature probes and pressure sensors), processes this information, and then turns it into actions via actuators (like injectors and EGR valves).

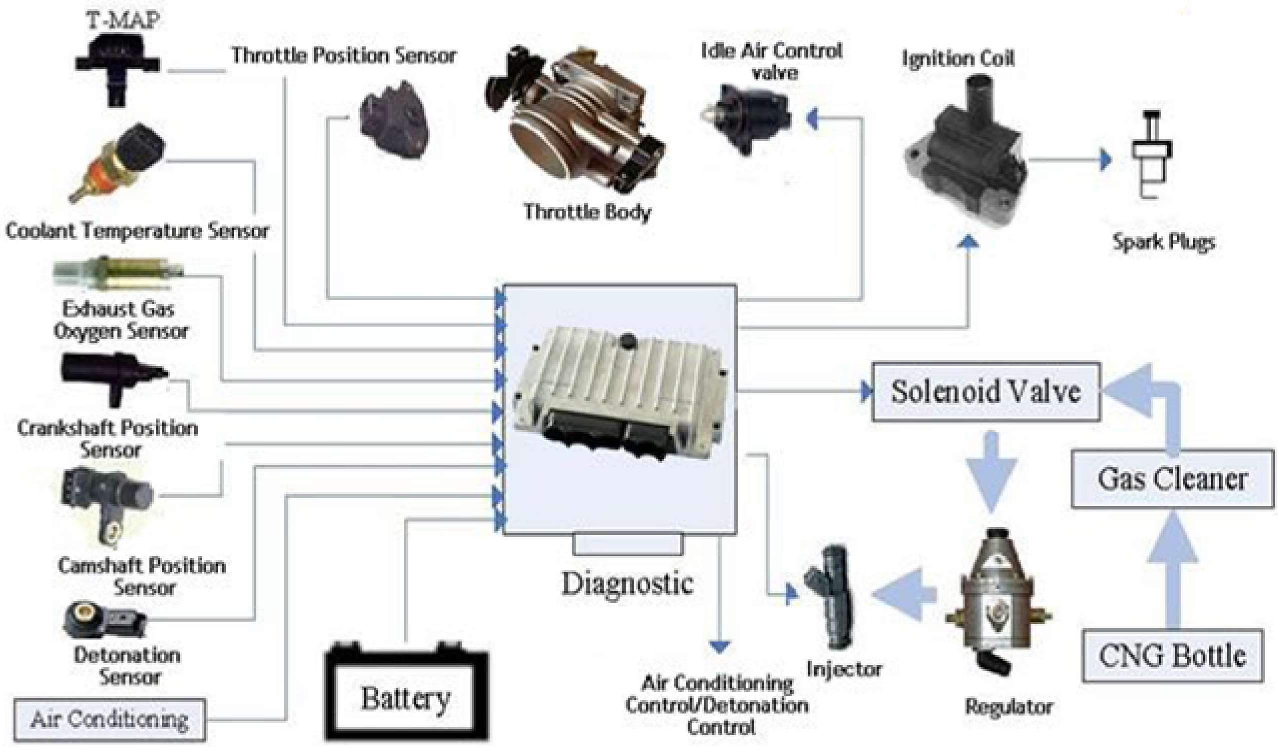


Figure IV.2. Electronic computer network with automotive subsystems

2.2. Applications of the Electronic Control Unit (ECU)

The ECU is used in various vehicle subsystems for control and management functions, including:

- **Engine Management**

  The ECU controls fuel injection, ignition timing, engine torque distribution, and other parameters to optimize engine performance, fuel economy, and emissions.

- **Automatic Transmission**

  In vehicles with automatic transmissions, the ECU controls gear shifting and other aspects of transmission operation for smooth and efficient changes.

- **Antilock Braking System (ABS)**

  The ECU monitors wheel speed sensors and controls the hydraulic pressure applied to the brakes to prevent wheel lock-up during braking.

- **Air Conditioning System**

  The ECU manages air conditioning parameters like temperature, fan speed, and air distribution to maintain a comfortable cabin environment.

2.3. Different Types of ECUs

While the term ECU (Electronic Control Unit) is often used specifically for the engine control unit, many other control units are present in a vehicle to manage various functions. The table below provides a non-exhaustive list of different types of ECUs.

Table IV.1. Different types of ECUs

Abbreviation	Designation	Utility
ECU or ECM	Engine Control Unit	System for managing the engine block
SCU	Speed Control Unit	Cruise control system, allows you to drive at a constant speed
TCU	Telematic Control Unit	Allows you to know the vehicle's positioning and GPS coordinates in real time
BCM	Brake Control Module	System representing ABS, providing braking assistance during emergency braking
BMS	Battery Management System	System for regulating the vehicle's battery

All these computers are connected to sensors and actuators that allow them to send and process information. Communication is therefore present between all these electronic components via communication buses.
This entire composition forms the vehicle's on-board electronics.

2.4. Importance of the Electronic Control Unit (ECU)

The electronic control unit is essential for modern vehicle operation due to its role in:

- **Performance Optimization**
  The ECU optimizes vehicle performance by adjusting the operating parameters of the engine, transmission, and other subsystems in real time.
- **Emission Reduction**
  By controlling and optimizing fuel combustion, the ECU helps reduce harmful vehicle emissions like nitrogen oxides (NOx) and fine particulates.

- **Safety**

  The ECU plays a crucial role in vehicle safety systems such as **ABS** (Antilock Braking System), **ESC** (Electronic Stability Control), and collision avoidance systems, which all contribute to improved road safety.

3. CAN communication bus

3.1. The Concept of Multiplexing

Multiplexing is a digital communication technique used to exchange information between different electronic components in a vehicle, such as the engine control unit (ECU), ABS, airbags, and climate control. This technique simplifies wiring, reduces costs, and improves communication between the various electronic systems.

Previously, every button or sensor in a car required its own dedicated wire, with multiplexing, the process is streamlined:

- A single communication line, known as a bus, connects multiple modules.
- Each message is encoded with an address, ensuring that only the intended recipient interprets it.

Multiplexing involves transmitting multiple signals (data, commands) over the same physical medium (a communication bus) instead of using dedicated wires for each function, this is applied to systems like:

- Window, light, and climate control.
- Communication between different ECUs.
- Safety systems (ABS, airbags).

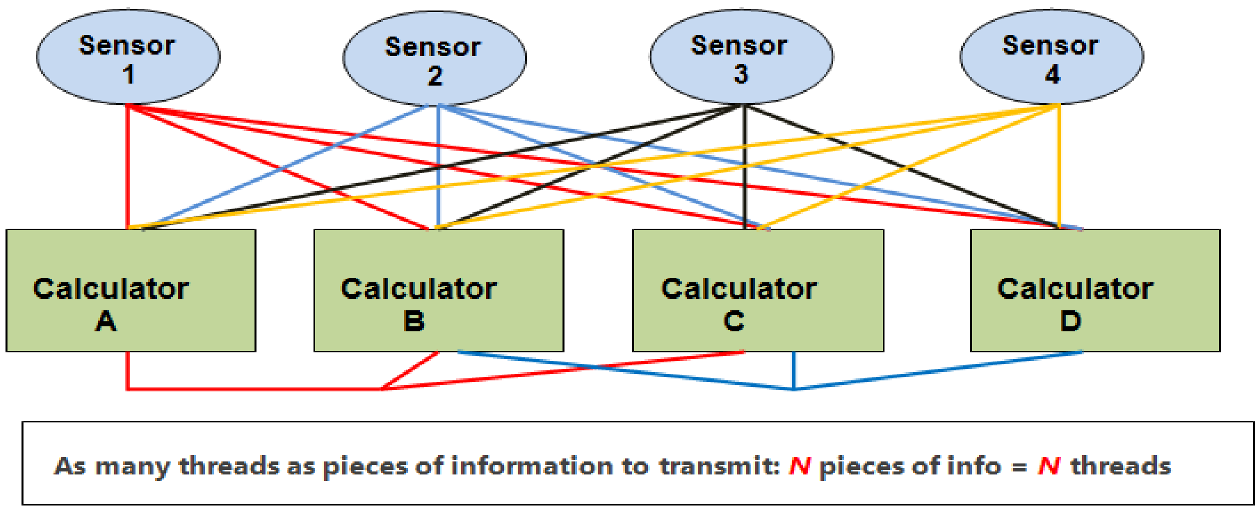


Figure IV.3. Wire frame architecture

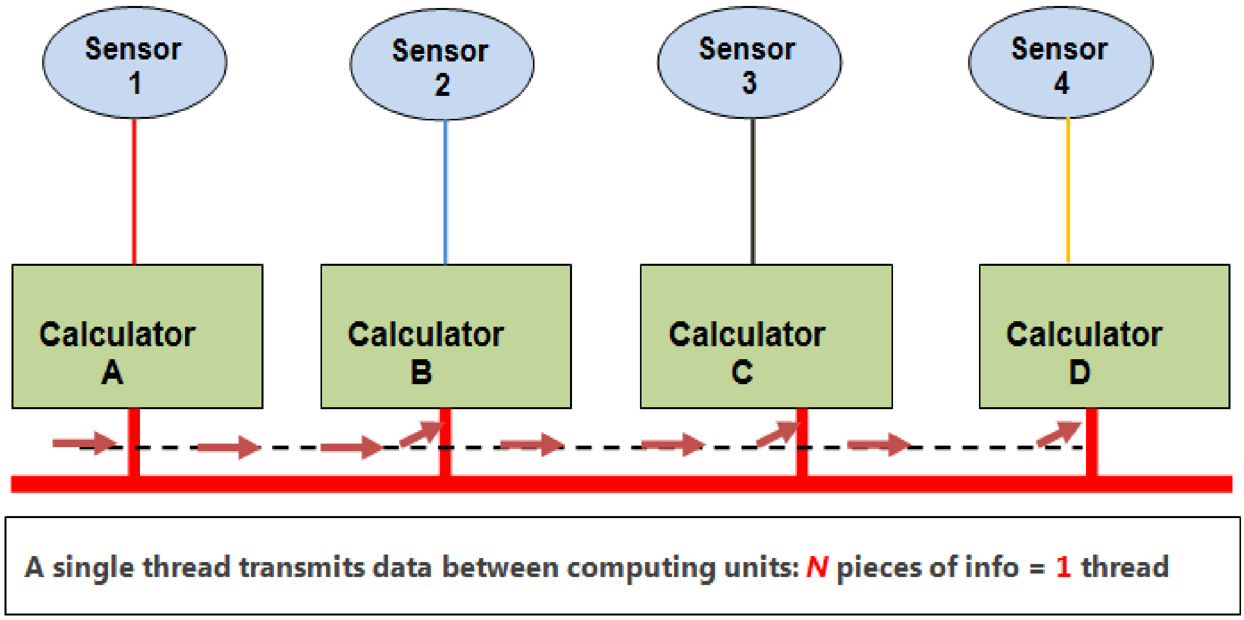


Figure IV.4. Multiplexed Architecture

A side view of a car, showing:

- The **A-pillars** at the front, on each side of the windshield.
- The **B-pillars** between the front and rear doors.
- The **C-pillars** at the rear window.
- The **D-pillars** at the very back (if it's an SUV or a station wagon).

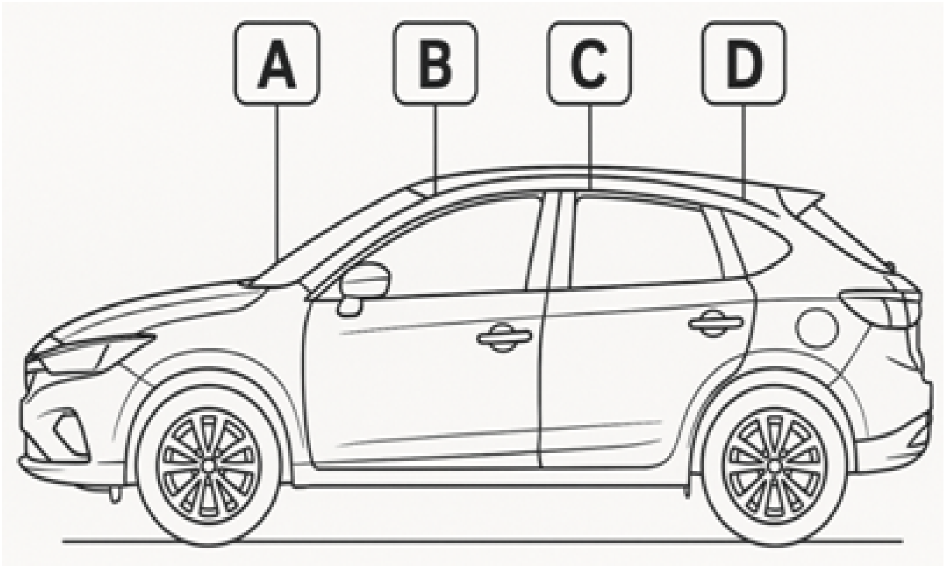


Figure IV.5. Diagram showing the multiplexing amounts in the car

3.2. The CAN Communication Bus

The CAN (Controller Area Network) Communication Bus is a digital communication system used in modern automobiles. It enables information exchange between the different subsystems of a vehicle.

The CAN bus is a serial communication protocol designed to allow multiple electronic control units (ECUs) in a vehicle or embedded system to communicate with each other reliably and efficiently. It uses a two-wire network to transmit data bidirectional and is particularly well-suited for harsh environments and applications that require robust, prioritized data transmission.

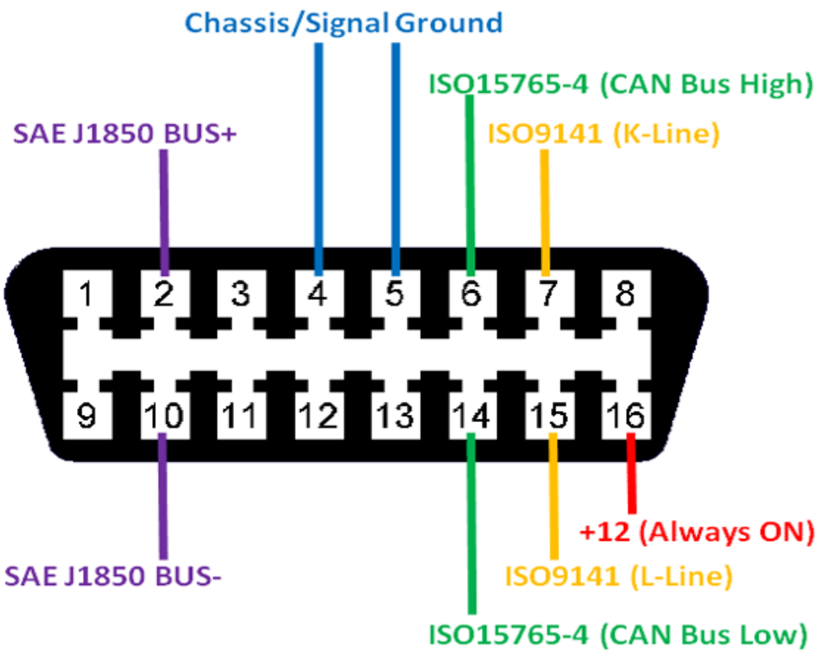


Figure IV.6.The CAN Bus

Due to the growing need for enhanced safety features (ABS, ESP, airbags) and increased comfort demands (memory for driving settings, passenger-specific climate control, navigation systems), this trend is only intensifying.

Starting in the early 1980s, the company Bosch developed a solution for multiplexing information within the car. This led to the creation of the CAN bus, which was standardized in the following years, beginning in 1983.

CAN components have become widespread and are now used in other sectors of embedded electronics, including medical devices, digital products, and electro-technical systems.

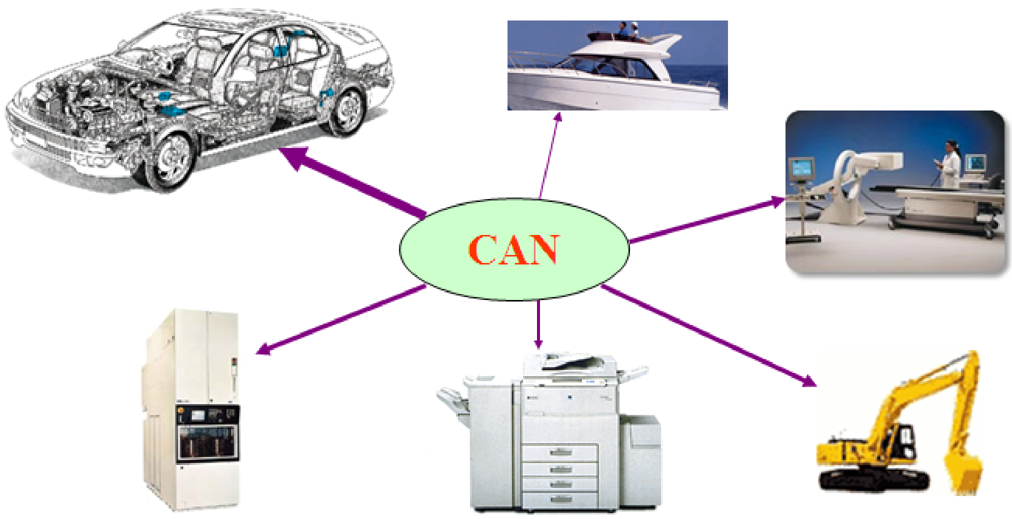


Figure IV.7.CAN Bus Application in On-board Electronics

3.3. The CAN Bus Physical Layer

The physical layer defines how a signal is transmitted. It ensures the physical transfer of bits between each node in accordance with the system's electrical and electronic properties. It's important to note that the network layer must be the same for every node.

The physical layer performs the following functions:

- Bit synchronization
- Bit representation (timing, coding, etc.)
- Definition of the electrical signal levels
- Definition of the transmission medium

It uses NRZ (Non-Return to Zero) coding, where the voltage level of the line is maintained for the entire duration that a bit is being generated.

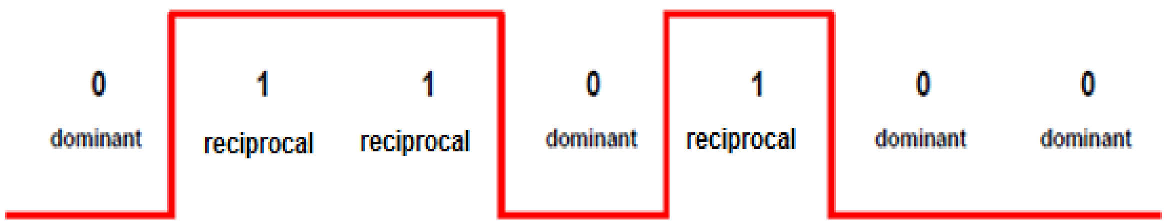


Figure IV.8. NRZ coding

The Bit Stuffing technique requires the transmitter to automatically add a bit of opposite value when it detects 5 consecutive bits in the values to be transmitted.

Figure IV.9. Frame on transmission before stuffing bits is set

Figure IV.10.Frame with stuffing bits (S)

Data transmission is carried out on a pair by differential transmission between the two lines (CAN H and CAN L). The bus line must be terminated by 120 Ohm resistors

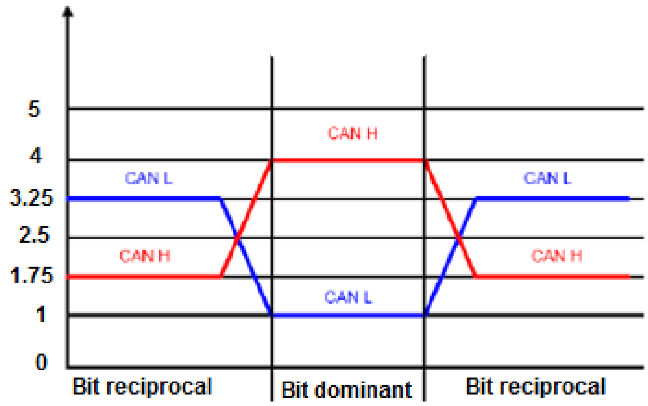


Figure IV.11.Voltage level (CAN) in low speed

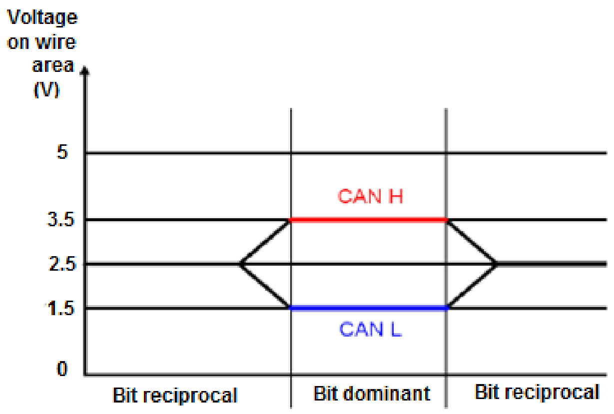


Figure IV.12.Voltage level (CAN) in high speed

The wiring is presented by a differential type wired pair: CAN H (CAN High), and CAN L (CAN Low).

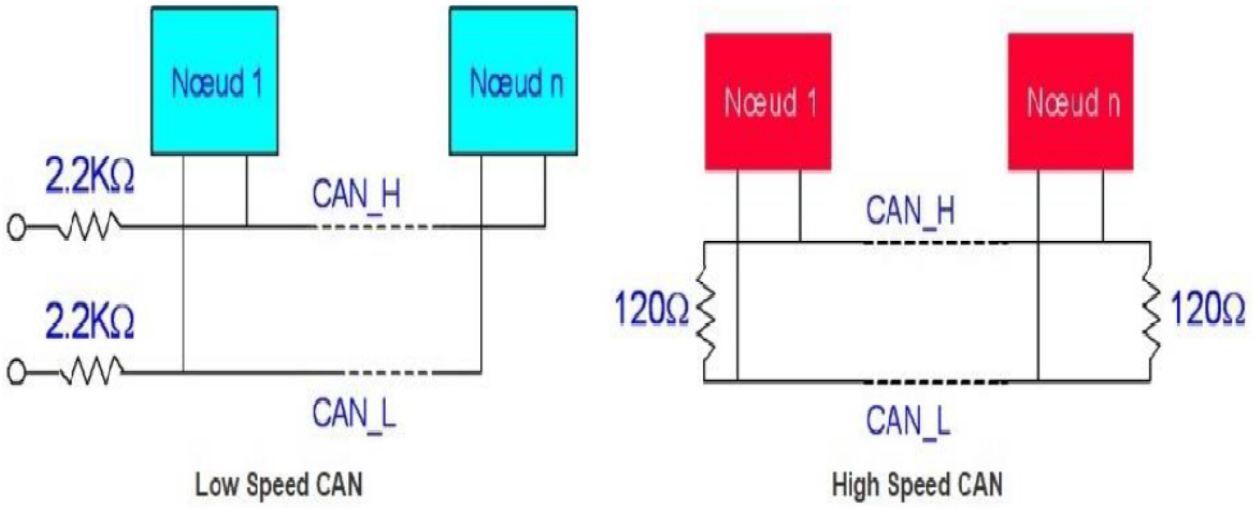


Figure IV.13.CAN Bus Wiring Diagram

Transmitting in differential pairs eliminates interference that can be induced on communication lines.

3.4. The CAN Communication Bus Works

The CAN bus is a communication bus that allows data to be exchanged between multiple nodes, or Electronic Control Units (ECUs). Each node or ECU can communicate with the others.

Data transmission is performed over a twisted pair of wires using differential signaling, which measures the voltage difference between the two lines: CAN-High (CAN H) and CAN-Low (CAN L). This method provides robust communication and noise immunity. The bus must be terminated at both ends with a 120-ohm resistor to prevent signal reflections.

Communications are carried out using message packets, and the transmission speed can reach up to 1 megabit per second (Mbps) for a high-speed CAN bus.

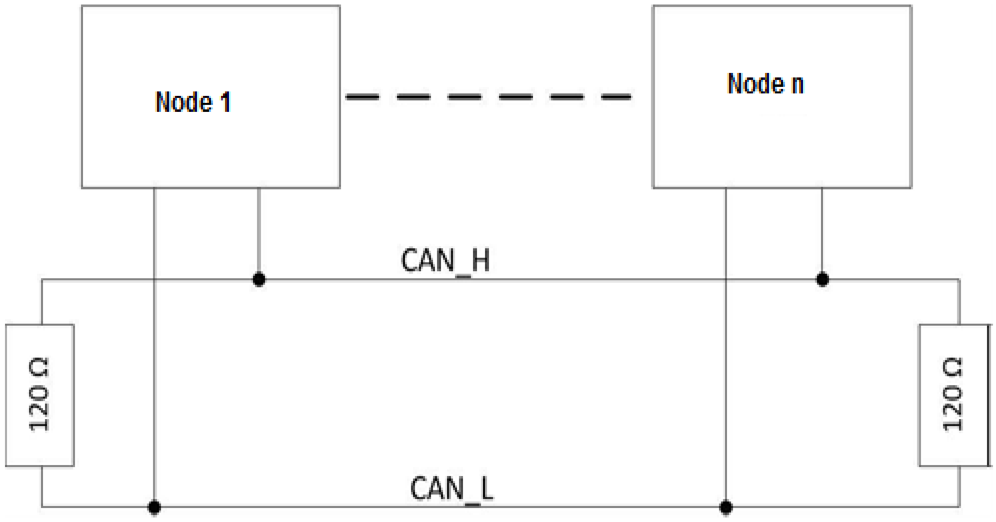


Figure IV.14.CAN Bus Operation

The CAN (Controller Area Network) communication bus is a serial communication network that links a vehicle's various electronic modules and subsystems.

Key Aspects of How the CAN Bus Works

- **Bus Topology**

  The CAN bus uses a bus topology, which means all network nodes (electronic modules) are connected to a single, shared communication bus.

- **Communication Protocol**

  CAN uses an asynchronous, message-based communication protocol. Messages are sent in frames that contain information such as a message identifier, the data to be transmitted, and priority.

- **Bus Arbitration**

  The CAN bus uses an arbitration mechanism to determine which node has priority to transmit a message. Nodes with the lowest message identifiers have the highest priority, ensuring that critical data gets through first.

- **Communication Speed**

  The CAN bus can operate at various communication speeds, typically ranging from**125 kbit/s** to **1 Mbit/s**, depending on the system's needs and the manufacturer's specifications.

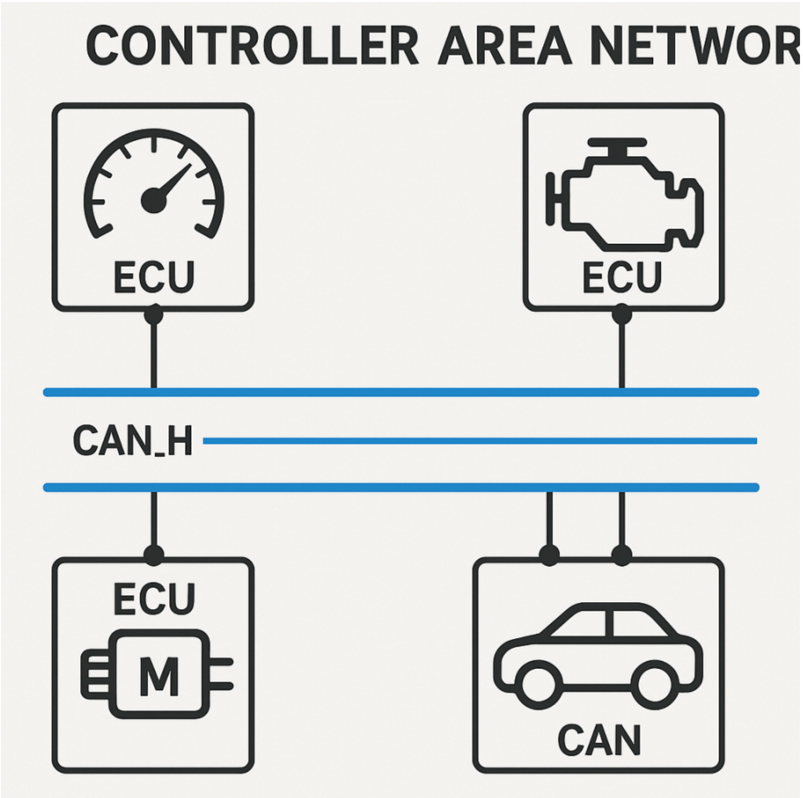


Figure IV.15.The CAN bus in the vehicle

The protocol structure of the CAN bus inherently possesses the following key properties:

- **Message Prioritization:** Messages are prioritized, ensuring that critical data is transmitted first.
- **Guaranteed Latency:** The system ensures predictable transmission times for messages.
- **Flexible Configuration:** The network can be easily configured and adapted.
- **Multiple Source Reception:** It allows for the reception of messages from multiple sources with time synchronization.
- **Multi-Master Operation:** All nodes can initiate a transmission.
- **Error Detection and Signaling:** The protocol includes mechanisms to detect and signal errors.
- **Automatic Retransmission:** Damaged messages are automatically retransmitted as soon as the bus is available again.
- **Error Distinction:** The system can distinguish between temporary errors and permanent node failures, and it automatically disconnects faulty nodes to maintain network integrity.

3.5. Advantages of the CAN Communication Bus

The CAN (Controller Area Network) bus offers several key advantages that have made it the standard for in-vehicle communication:

- **Reliability**

  CAN is designed to be robust and reliable, making it highly suitable for harsh automotive environments that are subject to extreme temperatures, electromagnetic interference, and vibrations.

- **Reduced Wiring**

  By using a single communication bus to connect all electronic modules in the vehicle, CAN significantly reduces the amount of wiring needed. This simplifies installation and lowers manufacturing costs.

- **Flexibility**

  The CAN allow for bidirectional communication between a vehicle's different subsystems, this enables efficient control and coordination among various electronic modules, such as the engine and transmission control units.

- **Diagnostic Capabilities**

  The CAN bus makes it easier to diagnose electronic issues within a vehicle. Mechanics can access error codes and sensor data from various electronic modules, streamlining the troubleshooting process.

3.6. Applications of the CAN Communication Bus

The CAN (Controller Area Network) bus is extensively used across numerous vehicle subsystems, including:

- **Engine Management:** Used to control fuel injection, ignition timing, and other engine management functions.
- **Automatic Transmission:** Controls gear shifting, clutch engagement, and other transmission-related tasks.
- **Braking Systems:** Manages the ABS (Antilock Braking System), electronic stability control, and other braking functions.
- **Climate Control Systems:** Regulates temperature, ventilation, and other air conditioning parameters.

3.7. Importance of the CAN Communication Bus

The CAN (Controller Area Network) bus is a vital part of the electronic architecture in modern vehicles. It enables efficient and reliable communication among the vehicle's various subsystems, which contributes to better performance, enhanced safety, and easier diagnosis of electronic issues.

3.8. Using the CAN Bus for Electronic Problem Diagnosis

The CAN bus plays a critical role in vehicle diagnostics, particularly with On-Board Diagnostics (OBD) systems. OBD is a specialized software system designed to perform automotive diagnostics and communicate with a vehicle's various ECUs to gather information on its status.

The acronym OBD stands for "On-Board Diagnostics." This system uses a dedicated port to allow a diagnostic tool to connect and retrieve all the information recorded by the vehicle's ECUs. The OBD port provides access to data on all vital and non-vital vehicle functions, giving a comprehensive picture of the health of each car part.

The error codes collected by the diagnostic tool are extremely valuable. They allow technicians to identify the precise origin of a malfunction, making it much easier to troubleshoot and repair a problem.

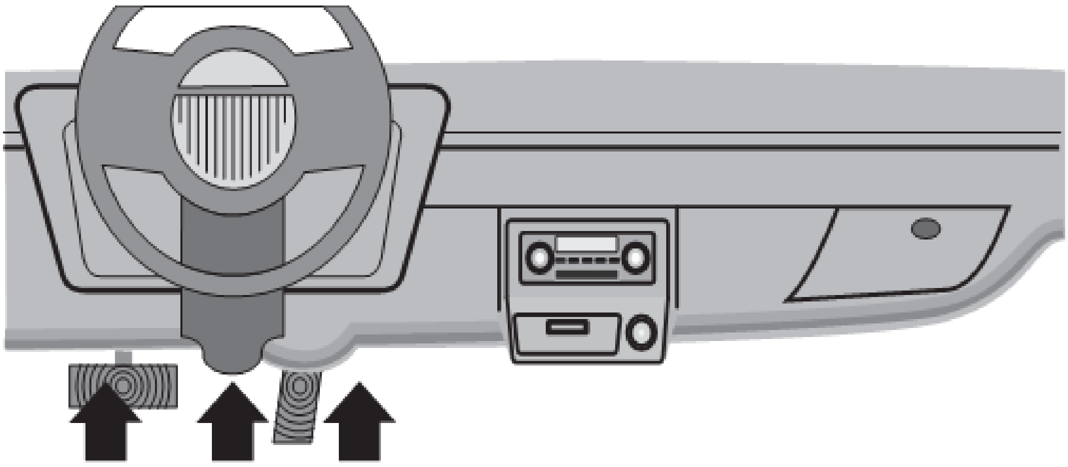


Figure IV.16. Data Link Connector (DLC) location

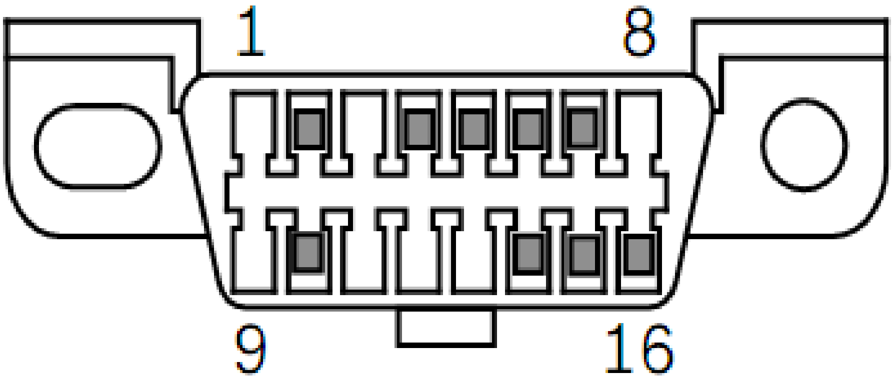


Figure IV.17.OBD II Data Link Connector Pinouts

Data Link Connector (DLC) Pins:

1. Reserved for manufacturer	**2.** J1850 Bus+	**3.** Reserved for manufacturer
4. Chassis Ground	**5.** Signal Ground	**6.** CAN High, J-2284
7. K-Line, ISO 9141-2 and ISO/DIS 14230-4		**8.** Reserved for manufacturer
9. Reserved for manufacturer	**10.** J1850 Bus-	**11.** Reserved for manufacturer
12. Reserved for manufacturer	**13.** Reserved for manufacturer	**14.** CAN Low, J-2284
15. L-Line, ISO 9141-2 and ISO/DIS 14230-4	**16.** Battery Power	

3.8.1. OBD II Diagnostic Trouble Codes (DTC)

OBD II (On-Board Diagnostics II) trouble codes are codes stored by a vehicle's computer system when it detects a problem. These codes identify a specific area of an error and serve as a guide to help you pinpoint the exact location of a problem on the vehicle. Diagnostic trouble codes are used to help determine the cause of a vehicle's issues.

- They consist of a five-digit alphanumeric code.
- The format and types of these generic codes are described below.

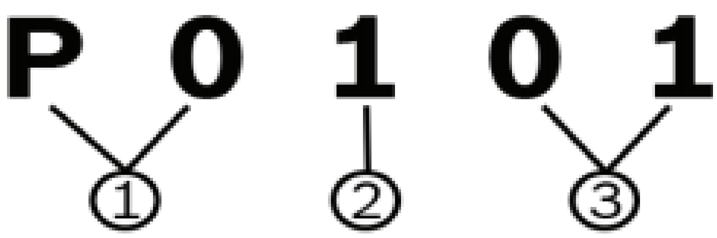


Figure IV.18.Fault code

Based on the context of OBD-II Diagnostic Trouble Codes, here is the English translation and explanation of the codes you've provided:

1. **DTC Category Codes**

The first letter of a DTC (Diagnostic Trouble Code) indicates the general system where the fault is located.

- **B**x = **B**ody (air conditioning, airbags, power seats)
- **C**x = **C**hassis (ABS, traction control)
- **P**x = **P**ower train (engine, transmission)
- **U**x = **U**nclassified/Network (e.g., communication between modules)

The second character (represented by "x") is a number that further classifies the type of code:

- **0** = Generic/SAE (Society of Automotive Engineers) code
- **1** = Manufacturer-specific code
- **2** = Generic /SAE code
- **3** = Manufacturer specific code

2. **Vehicle Specific System**

The third digit of the DTC points to a more specific subsystem within the primary category. For example, a "P" code might have a third digit to indicate whether the issue is with the fuel system, ignition system, or emissions system.

3. **Specific Fault Designation**

The last two digits of the DTC (the fourth and fifth characters) are used to provide a unique fault designation. This code provides the specific details of the malfunction, helping a technician pinpoint the exact problem, such as a sensor failure or a circuit malfunction.

Example

The code **P0101** indicates an issue with the range/performance of the mass air flow (MAF) circuit.

Note:

There are two main types of trouble codes:

standard codes and manufacturer-specific codes, Since the list of generic, or standard, codes is not always sufficient to cover all possible issues, manufacturers can add many specific codes for their vehicle models. Standard trouble codes were defined using a standardized format so that any diagnostic tool can read and decode them.

Trouble code design: Example

The first **letter** of a DTC indicates the DTC family:

- **P**: **P**owertrain, which includes the engine and transmission.
- **C**: **C**hassis.
- **B**: **B**ody.
- **U**: **U**ser **n**etwork communication.

The first **number** indicates whether the code is generic or not (the green digit):

- **0**: Generic fault.
- **1**: Manufacturer specific fault.

The final three digits are an incremental number (the purple digits). This number can be a hexadecimal value (0-9 plus A-F). For the P-codes, specific sub-families have been defined using the first digit of the three (the "3" in your example):

- **0, 1,** and **2**: For air/fuel mixture control.
- **3**: For the ignition system.
- **4**: For auxiliary emissions control.
- **5**: For engine idle control.
- **6**: For the on-board computer and auxiliary outputs.
- **7, 8,** and **9**: For transmission control.
- **A, B,** and **C**: For hybrid propulsion.

3.8.2. How to activate OBD2?

- ➢ Plug the interface into your vehicle's OBD connector.
- ➢ Plug the interface into your computer's USB port.
- ➢ Launch the diagnostic software Auto EOBD Facile.
- ➢ Turn on the vehicle's ignition.
- ➢ Click the " Connect " button

3.8.3. OBD-II Diagnostic Modes

Regardless of the communication protocol used, the OBD standard defines 10 diagnostic modes, which are described below.

Note

Manufacturers are not required to support all of these modes. Each manufacturer may also define additional modes.

- **Mode 1:** Returns current values for things like engine speed, vehicle speed, temperatures, etc.
- **Mode 2:** Returns freeze frame data for faults.
- **Mode 3:** This mode returns stored fault codes. These fault codes have been standardized across all vehicle brands and are categorized into 4 groups:
    - **P0xxx:** Standard faults related to the propulsion system (engine and transmission).
    - **C0xxx:** Standard faults related to the chassis.
    - **B0xxx:** Standard faults related to the body.
    - **U0xxx:** Standard faults related to communication networks.
- **Mode 4:** This mode allows you to clear stored fault codes and turn off the orange check engine light.
- **Mode 5:** This mode returns the results of self-diagnostics performed on oxygen/lambda sensors. It primatial applies to gasoline vehicles.
- **Mode 6:** This mode returns the results of self-diagnostics performed on non-continuously monitored systems.
- **Mode 7:** This mode returns unconfirmed fault codes. The codes used are identical to those in Mode 3.
- **Mode 8:** This mode returns the results of self-diagnostics performed on other systems (it is very rarely used in Europe).
- **Mode 9:** This mode returns vehicle information, such as:
    - The **VIN** (Vehicle Identification Number)
    - Calibration values
- **Mode 10:** This mode return permanent fault codes. The codes used are identical to those in Modes 3 and 7. Unlike Modes 3 and 7, these codes cannot be cleared using Mode 4. Only several drive cycles without the problem reappearing will clear the faults.

4. Sensor / Actuator Networks

Sensor/actuator networks in automobiles are communication systems that allow sensors and actuators from different vehicle subsystems to communicate with each other and with electronic control units (ECUs).

Modern vehicles contain dozens, or even hundreds, of sensors and actuators interconnected through these embedded networks.

These systems enable:

- Real-time monitoring of parameters like temperature, pressure, and speed.
- Control of actuators, such as motors, solenoid valves, and injectors.
- Communication between ECUs, including the engine control unit, ABS, and airbag systems.

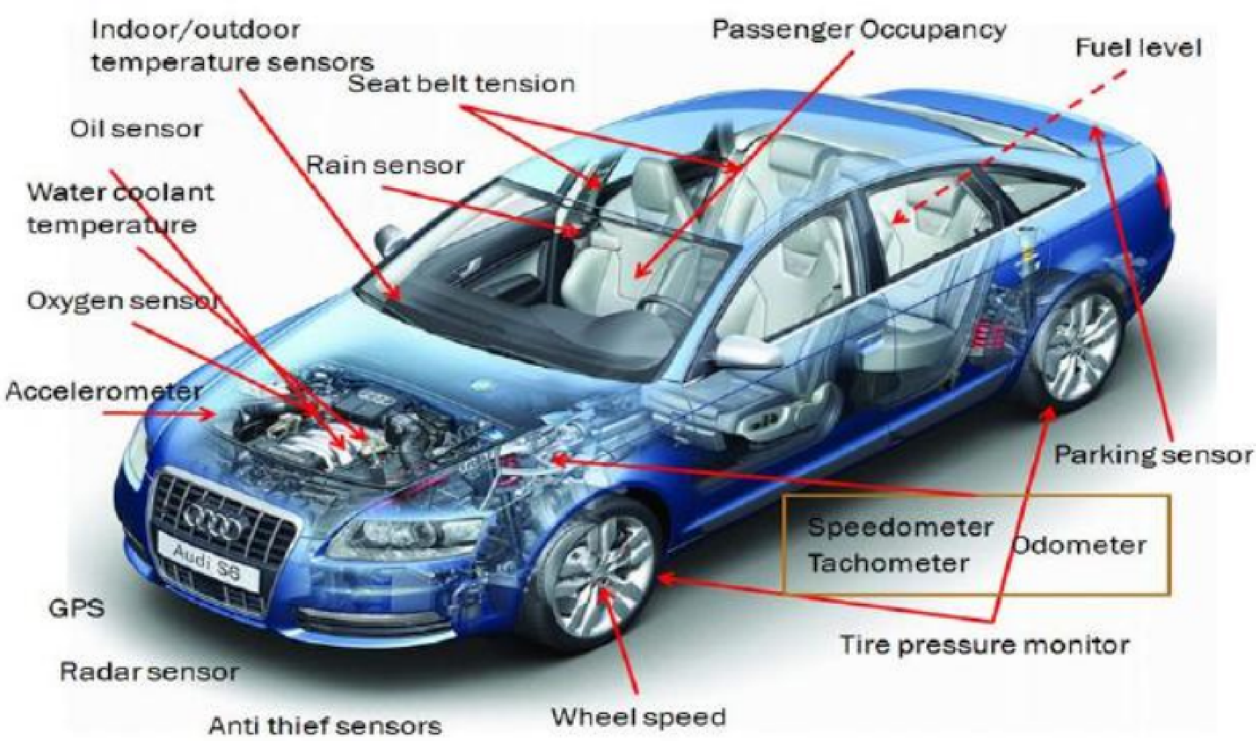


Figure IV.19. Sensor/actuator networks

4.1. How Sensor/Actuator Networks Work

Sensor/actuator networks in automobiles are communication systems that enable sensors to collect data on vehicle conditions and actuators to perform actions based on that data, here is how they generally work:

- **Data Collection**

  Sensors scattered throughout the vehicle's various subsystems collect data on parameters such as speed, temperature, pressure, position, etc.

- **Data Transmission**

  The sensors transmit the collected data to the electronic control units (ECUs) via the sensor/actuator network.

- **Data Analysis**

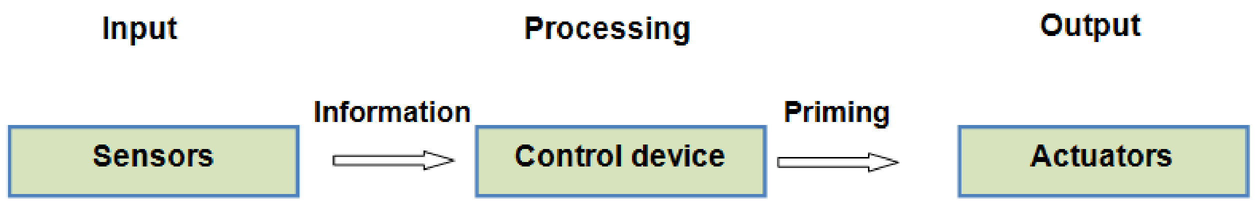
  The ECUs analyze the data received from the sensors to make decisions based on predefined parameters and control algorithms.

- **Actuator Activation**

  The ECUs send output signals to the actuators via the sensor/actuator network to perform actions such as opening or closing valves, adjusting fuel injection, or controlling steering.

4.2. Components of Sensor/Actuator Networks

All electronic systems, including those in vehicles, operate on the **Input, Processing, and Output (IPO)** principle of information processing.



- **Input**

  This is where information is gathered. In a car, the **sensors** act as the input components. They collect data about the vehicle's conditions, such as speed, temperature, and pressure.

- **Processing**

  This is the "brain" of the system. The **electronic control units (ECUs)** process the data received from the sensors. They analyze this information according to pre-programmed logic to make decisions.

- **Output**

  This is the action taken based on the processed information. The **actuators** are the output components. They perform a physical action, like adjusting the fuel injection, activating the brakes, or rolling down a window.

4.3. Communication Protocols

Several communication protocols are used in automotive sensor/actuator networks, including:

- **CAN (Controller Area Network)**

CAN is a widely used communication protocol in the automotive industry due to its reliability, robustness, and ability to support a large number of nodes. It's often used for power train, chassis, and body electronics.

- **LIN (Local Interconnect Network)**

  LIN is used for low-speed, low-cost communications, typically for low-priority sensors and actuators such as those in door locks or window controls.

- **Flex Ray**

  Flex Ray is used for high-bandwidth, real-time applications, such as critical safety systems like drive-by-wire or active suspension. It offers higher speed and more reliable timing than CAN.

Several protocols coexist depending on the needs in terms of flow, reliability and cost:

Table IV.2. Communication protocols in automobiles

Protocol	Speed	Typical Application
CAN	1 Mbps max	Critical transmission (engine, braking)
LIN	20 kbps	Low priority equipment (seats, windows) Low priority equipment (seats, windows)
Flex Ray	10 Mbps	Real-time systems (X-by-Wire)
Ethernet Automotive	1 Gbps+	Multimedia, software updates

4.4. Examples of Sensor/Actuator Networks:

Here are some examples of the components found within a vehicle's sensor and actuator networks:

- **Sensors**

  These components collect data about the car's condition and its environment.

  - **Pressure sensors:** Found in the Manifold Absolute Pressure (MAP) sensor to measure air pressure for the engine, or in tire pressure monitoring systems (TPMS).
  - **Position sensors:** Detect the position of components like the accelerator pedal or the steering wheel.
  - **Cameras/ LiDAR:** Used in Advanced Driver-Assistance Systems (**ADAS**) to "see" the road and surroundings.

- **Actuators**

  These components perform actions based on commands from the vehicle's electronic control units (ECUs).

  - **Electronically controlled injectors:** Regulate the precise amount of fuel delivered to the engine.
  - **Servomotors:** Found in systems like electric power steering, where they provide assistance to the driver.
  - **EGR Solenoid Valve:** Controls the flow of exhaust gas back into the engine's combustion chamber to reduce emissions.

4.5. Importance of Sensor/Actuator Networks

Sensor/actuator networks are critical to modern vehicles because they provide a backbone for communication and control.

Their key benefits include:

- **Feature Integration**

  These networks allow different vehicle functions and subsystems to work together seamlessly. This leads to a more efficient design and better coordination between components. For example, the engine control unit (ECU) can use data from a speed sensor to adjust fuel injection.

- **Diagnostics and Maintenance**

  The networks make it easier to diagnose electronic issues. Technicians can connect to the system to access data from sensors and check the command signals sent to actuators, quickly pinpointing where a problem might be.

- **Scalability**

  They allow for the addition of new sensors, actuators, and features without needing to significantly redesign the vehicle's electronic architecture. This is essential as new technologies, like advanced driver-assistance systems (ADAS) or infotainment, are added to vehicles.

5. Conclusion

The architecture of modern vehicle systems represents a complex fusion of mechanics, embedded electronics, and software technologies, marking a clear break from traditional automotive design.

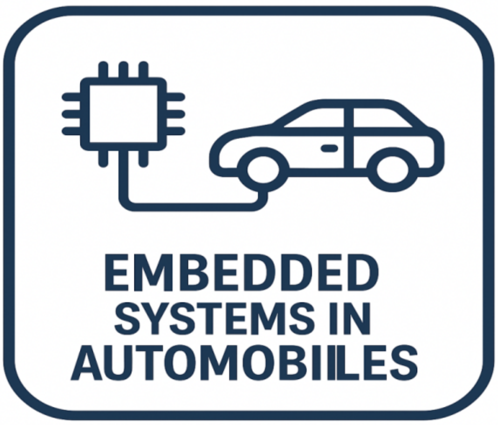
Throughout this text, we've seen that this architecture is based on a modular and interconnected structure electronic Control Units (ECUs) communication networks and various software layers work together to ensure performance and safety. This evolution brings numerous challenges, including managing increasing complexity, optimizing energy use, and the need for standardization. However, technological advancements like centralized architectures, the integration of AI, and the transition to electric and autonomous vehicles are opening up innovative possibilities.

Vehicle systems architecture is at the heart of the automotive industry's digital revolution. Its continued evolution towards more integrated, intelligent, and sustainable solutions is shaping a future of mobility that's safer, more connected, and more environmentally friendly. Mastering these architectures is therefore becoming a strategic issue for everyone in the automotive sector.

Chapter V

Embedded Systems in Automobiles

- ✓ *Understand the importance of embedded systems in automobiles*
- ✓ *Master hardware and software architecture*
- ✓ *Analyze the main embedded automotive systems*
- ✓ *Understand electronic stability control (ESP)*
- ✓ *Measure wheel rotation speed (encoder) and vehicle speed (Doppler effect).*



1. Introduction

The electronics and embedded computing in cars constitute such a complex network that new computer tools are needed to test and diagnose failures or to perform remote diagnostics. These systems include electronic ignition, injection, anti-lock braking systems, airbags, electronic stability control, and more. The massive introduction of embedded functions in recent years has caused a true revolution in the automotive industry.

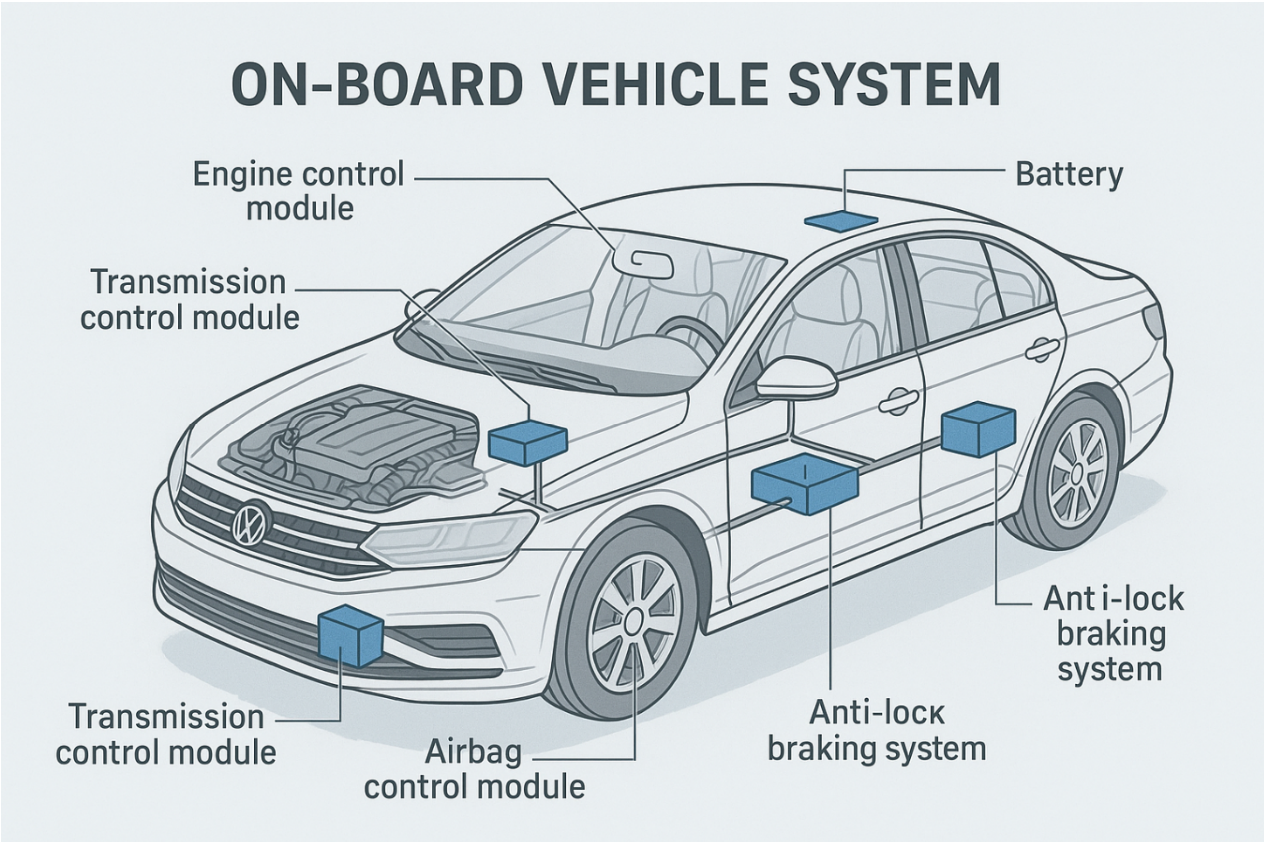


Figure V.1.Architecture of an automotive embedded system

2. Embedded Sensors Systems

Embedded sensor systems are at the heart of modern devices such as automobiles, drones, medical devices, robots, and the Internet of Things (IOT), they enable the measurement, acquisition, processing, and transmission of information about the physical environment.

2.1. Architecture of an Embedded Sensor System

An Embedded sensors system is an integrated set of sensors, a microcontroller, a communication interface, and potentially actuators, allowing for the perception of and interaction with the environment.

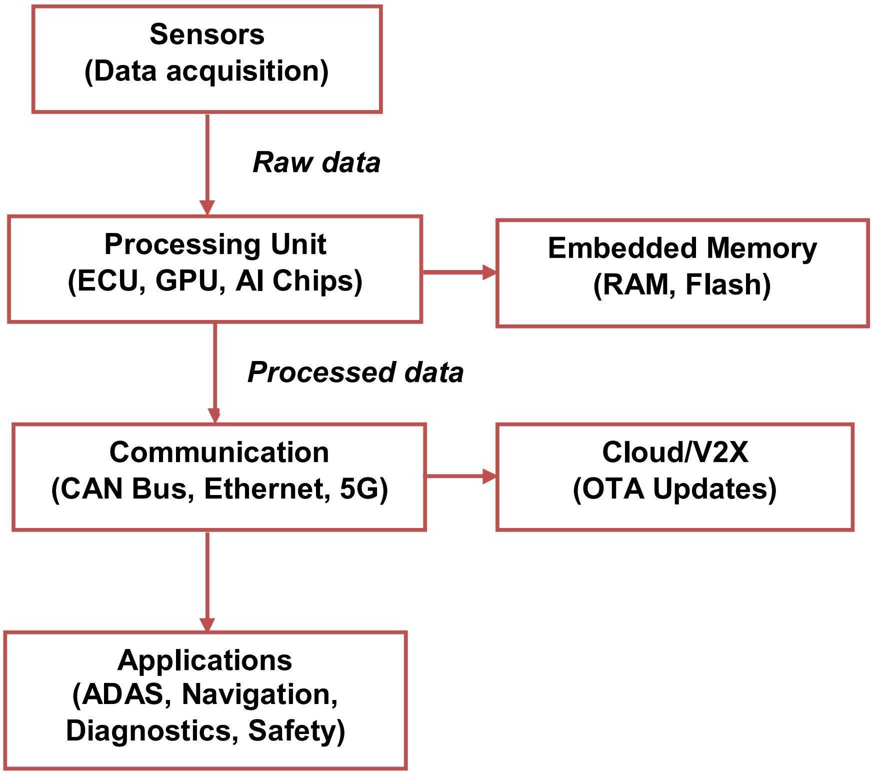


Figure V.2.Architecture of an embedded system

Figure 5.2 illustrates the typical operating path of an automotive on-board sensor system, often used in connected or autonomous vehicles:

2.1.1.Sensors (Data Acquisition)

Sensors (cameras, radars, LIDARS, temperature sensors, etc.) collect raw data from the environment or the vehicle.

2.1.2.Processing Unit (ECU, GPU, AI Chips)

The raw data is sent to a processing unit (such as an ECU, a GPU, or dedicated AI chips) for analysis and transformation. For example, a raw image can be processed to detect pedestrians or road signs.

2.1.3.Embedded Memory (RAM, Flash)

The processed data is temporarily stored in embedded memory (RAM for fast access, Flash for persistent storage) before being transmitted or used.

2.1.4.Communication (CAN Bus, Ethernet, 5G)

The processed data is transmitted via communication protocols (such as the CAN Bus for internal vehicle communications, or Ethernet/5G for external connections) to other systems or to the cloud.

2.1.5.Cloud/V2X (OTA Updates)

In the **cloud** or via **V2X (Vehicle-to-Everything)** infrastructures, data can be aggregated, analyzed on a large scale, or used for Over-The-Air (OTA) software updates.

2.1.6.Applications (ADAS, Navigation, Diagnostics, Safety)

Finally, the data is used to power concrete applications such as:

- **ADAS:** Advanced Driver-Assistance Systems (emergency braking, lane keeping).
- **Navigation:** Real-time map updates.
- **Diagnostics:** Monitoring the vehicle's status.
- **Safety:** Safety functions (automatic emergency call).

2.2. General Operation of an Embedded System in a Vehicle

The operating cycle of an embedded sensor system in an automobile generally follows a well-defined sequence, allowing for the real-time collection, processing, and use of data. The main steps are:

2.2.1. Data Acquisition (Sensing)

Sensors (temperature sensors, accelerometers, cameras, radar, etc.) measure a physical quantity (speed, pressure, distance, etc.).

- A speed sensor (ABS) detects the rotation of the wheels.

2.2.2. Signal Conditioning

This involves amplification, filtering (noise reduction), and conversion of the analog signal into a digital one (ADC).

- A boost pressure sensor (turbo) sends a raw signal that is filtered and converted into a digital value.

2.2.3. Data Processing

The microcontroller (ECU) processes the data (calculations, comparison with thresholds, control algorithms).

- The engine ECU adjusts fuel injection based on data from the oxygen sensor (lambda probe).

2.2.4. Communication via the Embedded Network (Data Transmission)

The data is transmitted via buses (CAN, LIN, Flex Ray) or Automotive Ethernet to other ECUs.

2.2.5. Decision and Action (Decision & Actuation)

The ECU makes a decision (emergency braking, air-fuel mixture adjustment).

- A signal is sent to the **actuators** (motors, solenoid valves, etc.).
- The ESP (Electronic Stability Program) brakes a specific wheel in case of a loss of traction.

2.2.6. Monitoring & Diagnostics

This involves continuous verification of proper operation (self-tests, fault detection).

- Fault codes (OBD-II) are sent in case of an anomaly.
- A defective tire pressure sensor (TPMS) triggers a warning light on the dashboard.

3. Anti-lock braking system (ABS)

The acronym "ABS" comes from the German term "Anti-Blockier-System," also known in English as "anti-lock braking system" or in French as "système de freinage antiblocage." During emergency braking, the significant force applied to the brake pedal often causes the wheels to lock up, which primarily lead to:

- ✓ An increase in stopping distances.
- ✓ The loss of steering control of the vehicle.
- ✓ A decrease in vehicle stability.

The technological solution to this problem is the integration of an anti-lock braking system (ABS), which allows you to:

- ✓ Avoid wheel lock-up during sudden braking.
- ✓ Reduce the stopping distance while maintaining steering control.

Ultimately, this system is an active safety feature that helps the driver maintains directional control of the vehicle.

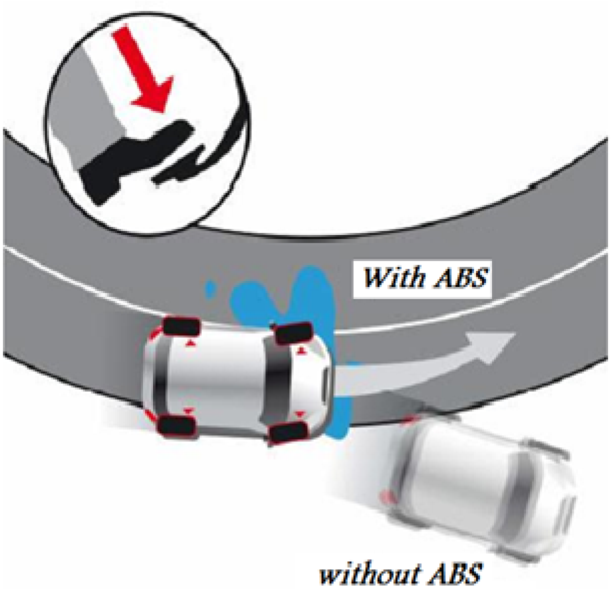


Figure V.3. The importance of ABS system

Anti-lock Braking System (ABS) is an active safety system used in motor vehicles to prevent wheels from locking during emergency braking or on slippery surfaces. ABS helps reduce braking distances, improve vehicle stability, and prevent collisions, making it an essential device for ensuring road safety. Understanding how it works and its importance is therefore essential for drivers and automotive professionals.

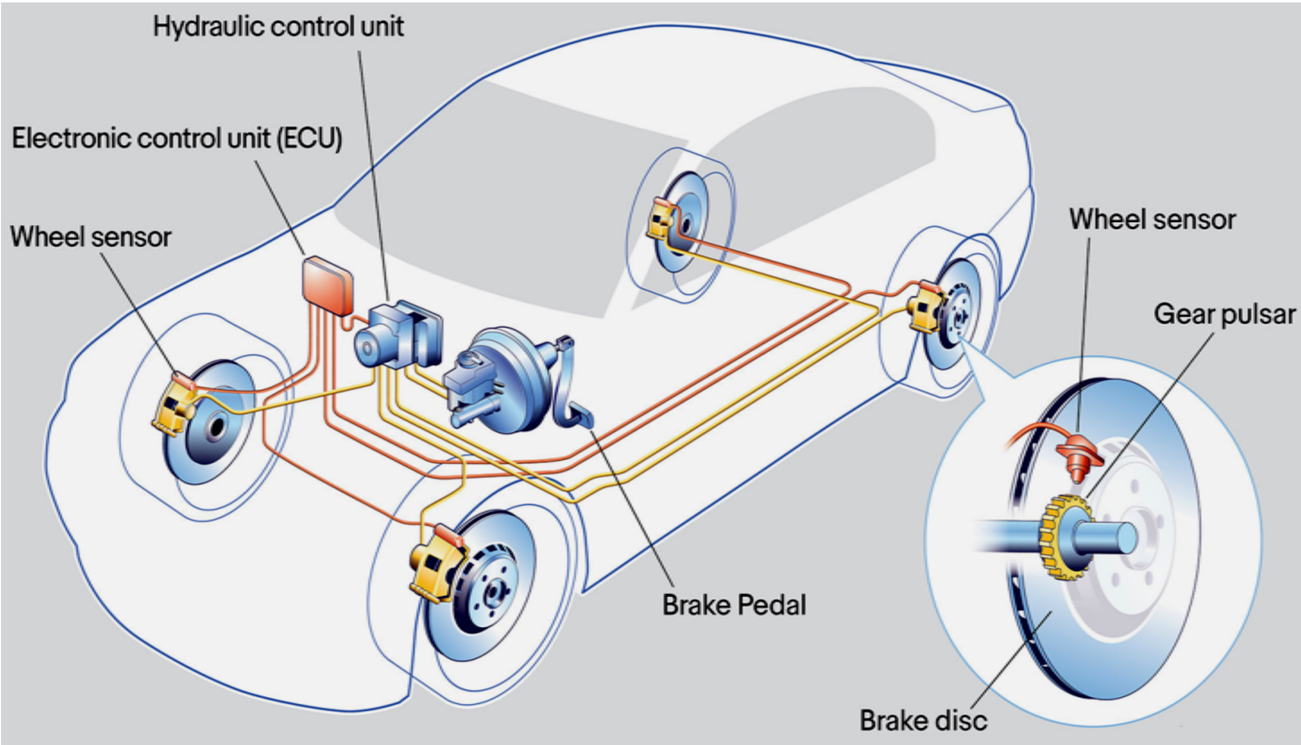


Figure V.4. Anti-lock Braking System (ABS)

3.1. Key system components (ABS)

The ABS (Anti-lock Braking System) is composed of three main elements that work together to prevent wheel lock-up during braking.

3.1.1. Wheel Speed Sensors

These sensors are located on each wheel and are responsible for measuring the rotational speed of the wheel at all times. They send this information to the ECU (Electronic Control Unit).

Figure V.5.Wheel Speed Sensors

3.1.2. Electronic Control Unit (ECU)

The ECU is the "brain" of the ABS. It continuously monitors the data received from the wheel speed sensors. If it detects that a wheel is about to lock up (its speed suddenly drops significantly), it sends a command to the hydraulic modulator.

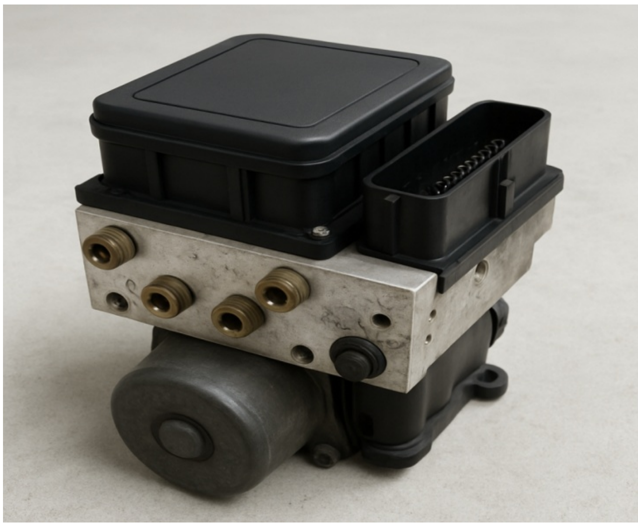


Figure V.6.Control Module with these ABS system auxiliaries

3.1.3. Hydraulic Modulator

The hydraulic modulator is an assembly that manages the brake fluid pressure to each wheel. When the ECU sends a signal, the modulator can quickly adjust the pressure in the brake lines to a specific wheel. It can rapidly increase, hold, or decrease pressure to prevent the wheel from locking, all while the driver is pressing on the brake pedal. This process happens multiple times per second, creating the pulsating feeling often felt through the brake pedal during hard braking.

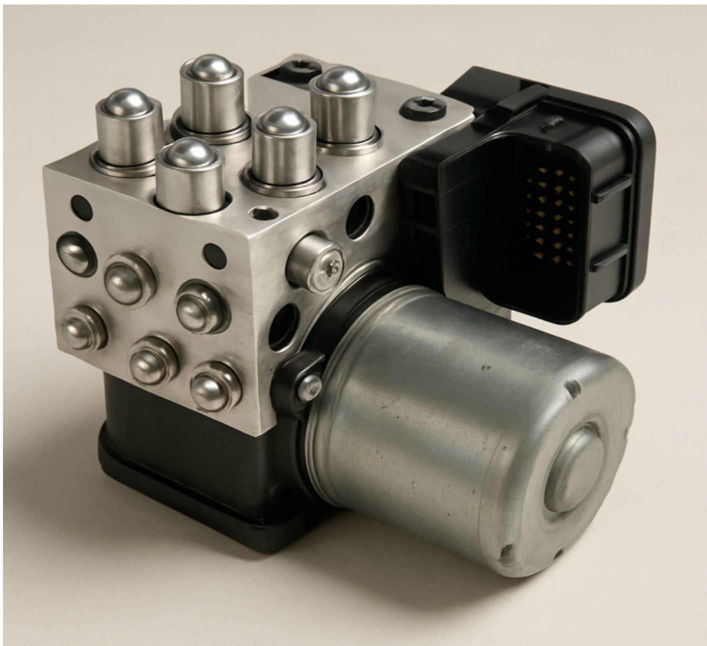


Figure V.7. ABS Hydraulic Actuators

Figure V.8.ABS housing

3.2. How ABS Works

- **Detection of Wheel Lock-Up**

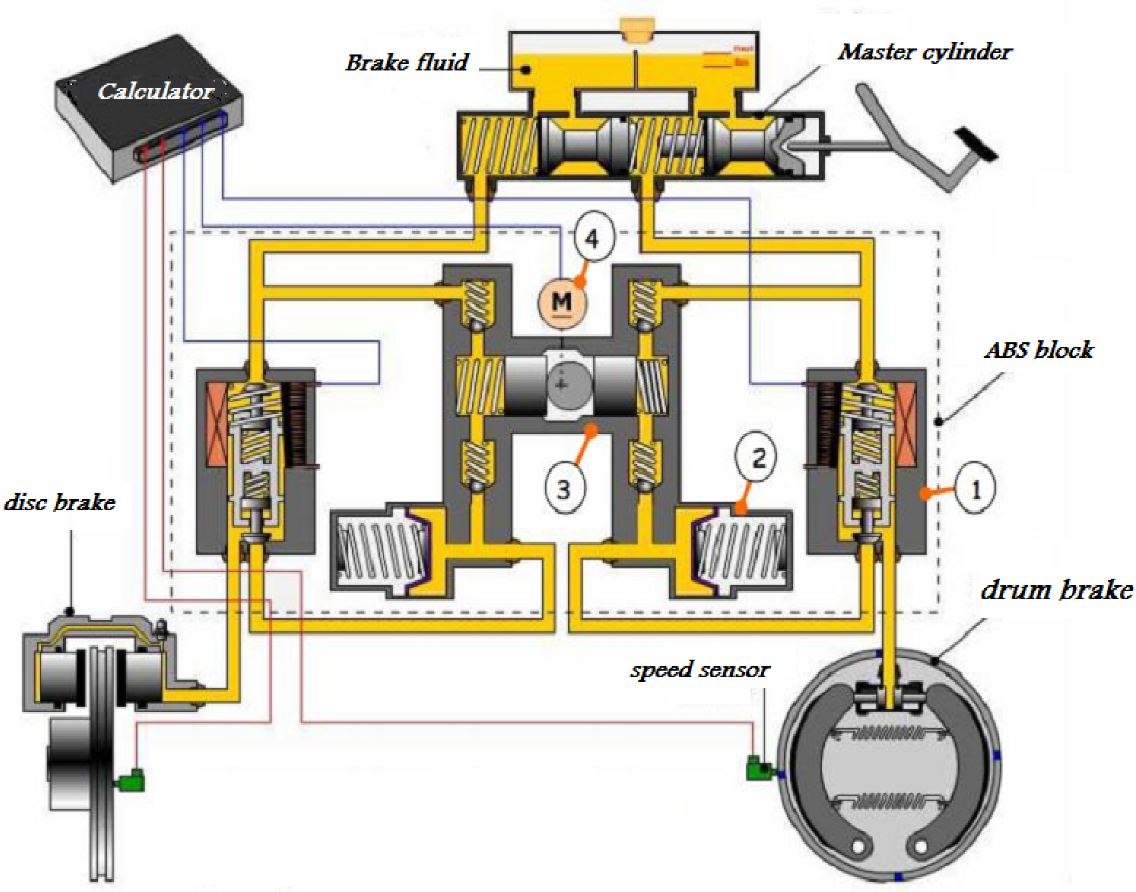
  Speed sensors located on each wheel continuously measure their rotational speed. If a sensor detects that a wheel's rotational speed suddenly decreases, indicating a risk of lock-up, the ABS system activates.

- **Brake Pressure Modulation**

  The ABS system modifies the hydraulic pressure applied to each wheel's brakes in a pulsating manner. It temporarily releases the brake pressure when a lock-up is detected, then quickly reapplies it, allowing the wheel to continue turning.

- **Maintenance of Directional Control**

  By preventing the wheels from locking, ABS maintains the vehicle's steering system, allowing the driver to retain directional control and avoid collisions during emergency braking.



1- Intake/exhaust solenoid valve	2- Accumulator	3- Pump	4- Electric motor

Figure V.9. Structural diagram of an ABS system

4. Anti-Slip Regulation (ASR)

ASR (Anti-Slip Regulation): This system primarily acts on the engine torque to improve the grip of the drive wheels. It intervenes when the wheels begin to slip by adjusting engine power and applying selective braking to restore optimal traction. ASR is particularly effective on slippery surfaces such as snow or ice, making it easier to start and accelerate without losing control.

The wheel anti-skid system is also known by the English terms "Anti-Slip Regulation" (ASR) and "Traction Control System" (TCS).

The traction control system is an active automotive safety system designed to help a vehicle take advantage of the available road grip when accelerating on a slippery surface.

Its main role is to:

- ✓ Prevent the driving wheels from spinning in all circumstances, such as when starting on a hill on a snowy road.

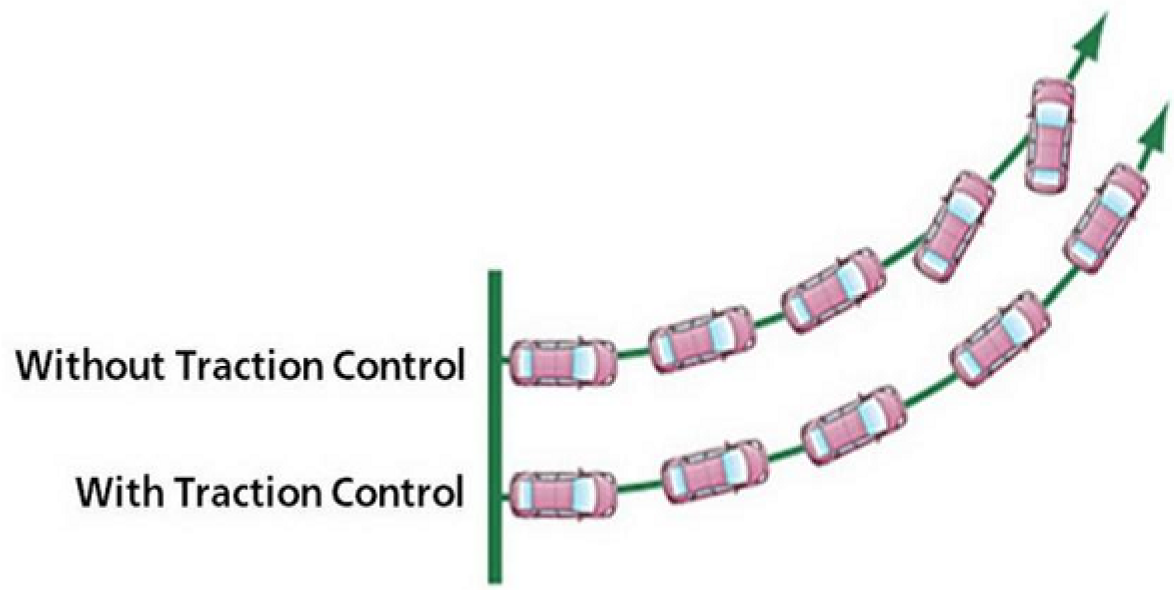


Figure V.10. The importance of ASR system

When a vehicle without traction control attempts to accelerate on a slippery surface like snow, ice, or gravel, its wheels are likely to spin. The tires turn rapidly on the road's surface without gripping, and as a result, the vehicle does not accelerate. The traction control system intervenes when it detects that the wheels are about to spin, helping the driver get the most out of the road's grip.

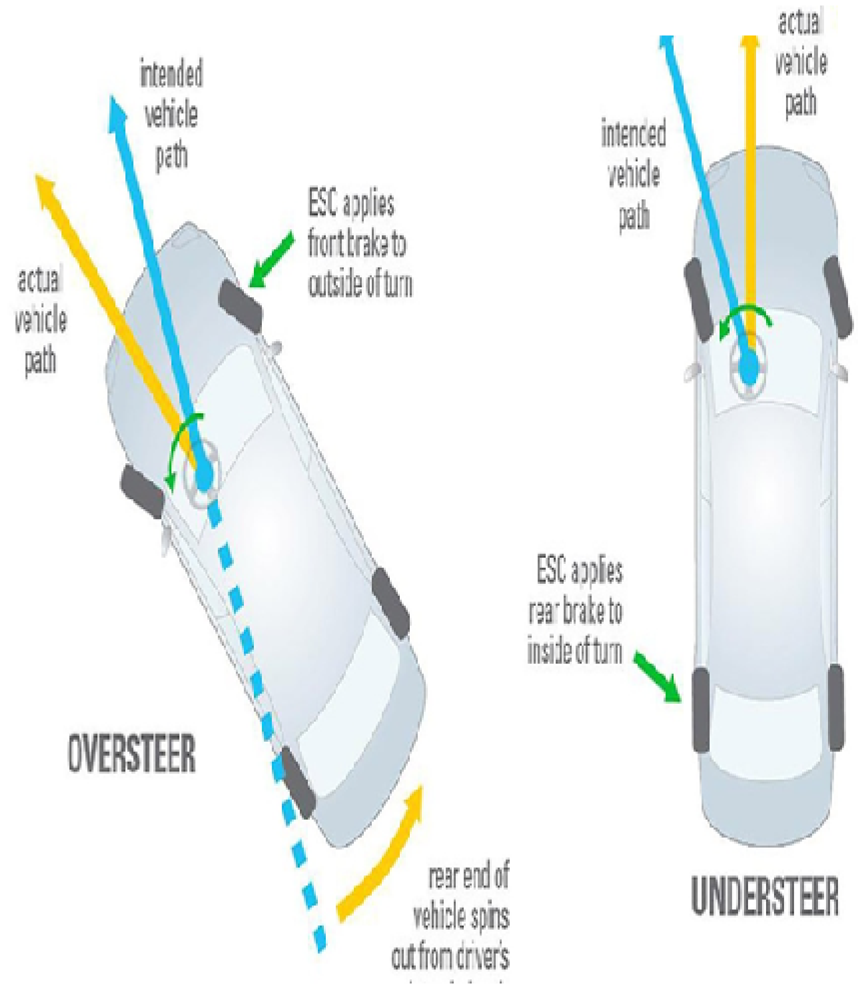


Figure V.11.Anti Skid System (ASR)

4.1. Components of an anti-skid system (ASR - Anti Slip Regulation)

The components of a Wheel Anti-Skid System (ASR), also known as a Traction Control System (TCS), are largely the same as those of an Anti-lock Braking System (ABS) because they share the same architecture. The key components include:

4.1.1. ABS or ASR?

While both systems act differently, they are related and use the same electronic control unit (ECU) and speed sensors because the anti-skid system works in conjunction with ABS.

- **ABS** prevents wheel lock-up during hard braking and helps you maintain vehicle control.

- **ASR**, on the other hand, reduces engine power to limit the traction force (or engine torque) on the drive wheels as soon as one wheel begins to spin faster than the others.

The Dynamic Stability Control system provides increased safety for the driver, but it does not absolve them of their obligations under the Highway Code. Thus, risky driving in dangerous areas increases the risk of collision. In the most extreme driving conditions, even the actions of various active safety devices cannot prevent fatal accidents from occurring.

4.1.2. Key ASR Components

- **Wheel Speed Sensors**

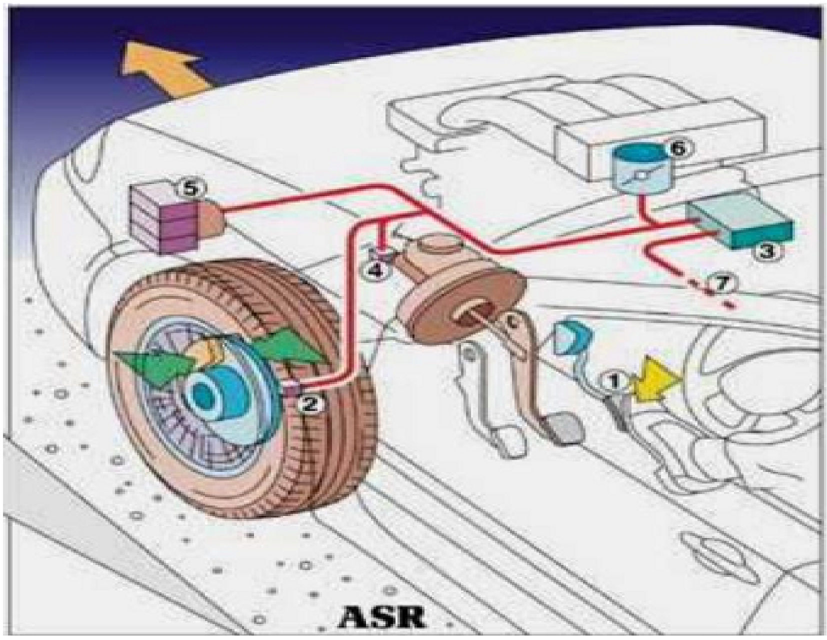
  These sensors measure the rotational speed of each wheel and detect differences in speed that indicate wheel slip.

- **ASR Control Module**

  The ASR control module analyzes data from the wheel speed sensors and makes decisions to reduce the spinning of the drive wheels.

- **Engine Control Actuators**

  These actuators are used to adjust the engine torque sent to the drive wheels, based on instructions from the ASR control module.



1. Accelerator pedal
2. Wheel speed sensor
3. Calculator
4. Brake pressure sensor
5. ABS Control Unit
6. Motorized throttle body / Injection pump
7. CAN (Controller Area Network, Node assembly)

Figure V.12. Structural diagram of an ASR system

4.2. How ASR Works

All these systems are electronic, which means they send a signal to a control unit that then issues a command. This signal is usually sent by a sensor installed in the vehicle's wheel, within its braking system, or even in its gearbox.

Accelerometers, as well as sensors for balance, temperature, or atmospheric pressure, can also be installed on the vehicle to measure its speed, its stability on the road, the G-forces it generates, or the ambient temperature.

Today's vehicles even use cameras to gather a maximum amount of information. A control unit then analyzes the collected information based on parameters predetermined at the factory.

This control unit then sends a message to the vehicle's anti-lock braking system (ABS), the engine, the all-wheel drive, and in some cases, even the gearbox, to limit power and torque while applying an independent braking force from one wheel to another.

While the first anti-skid and stability control systems were very rudimentary, intrusive, and not very precise, modern systems operate with much more flexibility and accuracy. This characteristic comes from the fact that these systems collect much more data than before. This data is routed to a significantly more powerful control unit, capable of assimilating the information and issuing a command more quickly. In the case of electric vehicles, the reaction time of these systems is even shorter because an electric motor can quickly modulate its rotational speed.

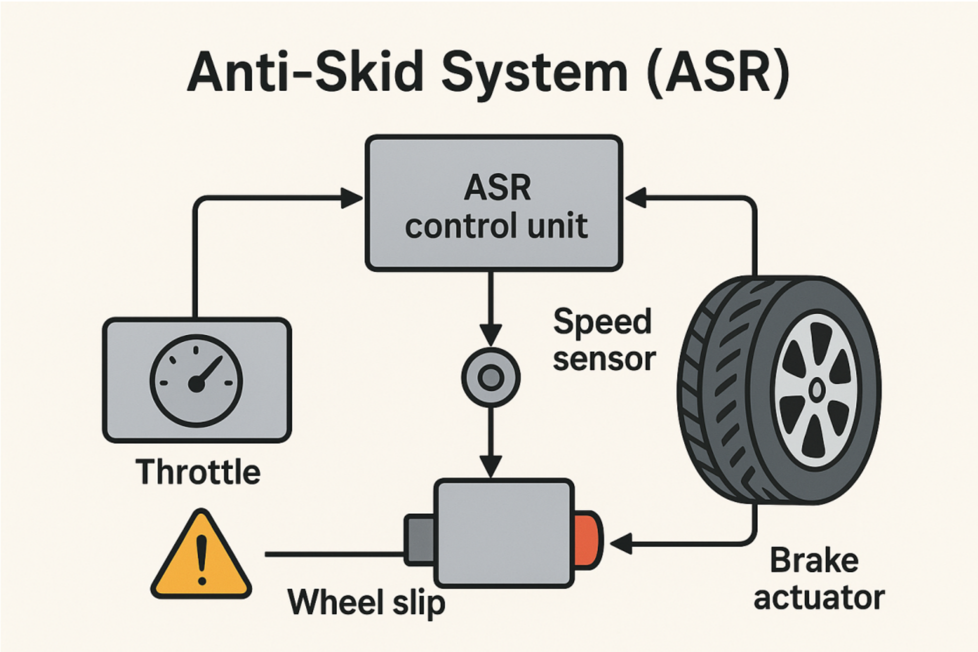


Figure V.13.Anti- skid System (ASR)

The operation can be summarized in the following steps:

- **Slip Detection**

  Wheel speed sensors continuously measure the rotational speed of the wheels. When a sensor detects excessive slipping of a drive wheel compared to another, the ASR system activates.

- **Engine Torque Reduction**

  The ASR system momentarily reduces the engine torque sent to the spinning drive wheels by adjusting the electronic throttle management or limiting the fuel flow.

- **Vehicle Stabilization**

  By limiting the spinning of the drive wheels, ASR helps stabilize the vehicle during acceleration, minimizing the risk of skidding and loss of control.

5. Electronic Stability Program (ESP)

The provided text explains that Electronic Stability Program (ESP), also known as Electronic Stability Control (ESC), is a crucial active safety system in modern cars. It's designed to improve a vehicle's stability and control during emergency situations or difficult driving conditions.

By helping to stabilize the vehicle, ESP contributes to reducing the risk of accidents and improving overall road safety.

5.1. How ESP Works

ESP is a sophisticated system that works by continuously monitoring the vehicle's motion and the driver's intended direction. It uses a network of sensors, including :

- **Wheel speed sensors:** Detect if a wheel is spinning or locking up.
- **Steering angle sensor:** Determines the direction the driver is trying to steer.
- **Yaw rate sensor:** Measures the vehicle's rotation around its vertical axis.

The ECU (Electronic Control Unit), the brain of the system, compares the driver's steering input with the vehicle's actual movement. If it detects a difference—indicating that the car is starting to under steer (plowing straight ahead in a turn) or over steer (the rear end sliding out)—the ESP system takes immediate action.

To correct the vehicle's path, ESP can:

- **Selectively apply the brakes** to individual wheels. For example, to correct over steer, it might brake the outside front wheel to help bring the back of the car in line.

➢ **Reduce engine power** to decrease the force that is causing the loss of traction.

These actions happen in milliseconds, often before the driver is even aware of the loss of control, helping to steer the vehicle back on its intended path.

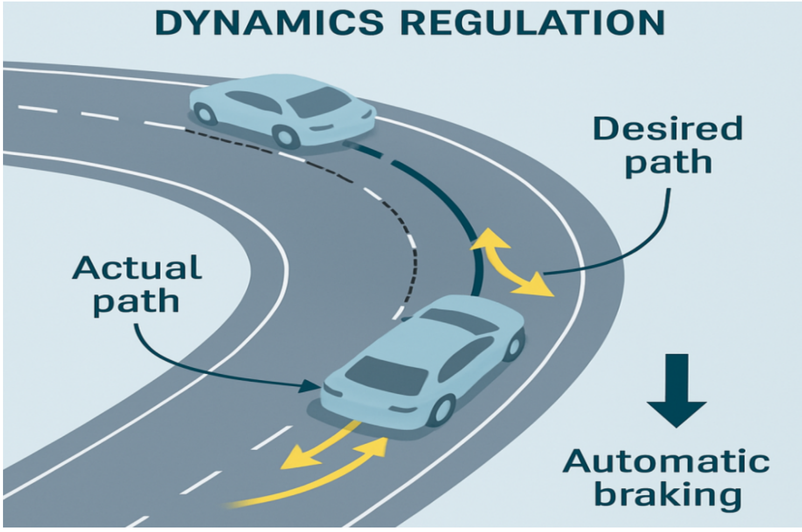


Figure V.14.Electronic Stability control (ESP) system

5.2. Components of the Vehicle Electronic Stability Control System

The Electronic Stability Control (ESC) or Electronic Stability Program (ESP).

The key components of this system are:

- **Wheel Speed Sensors:** These sensors measure the rotational speed of each wheel and detect any differences in speed that could indicate a skid.
- **Steering Angle Sensors:** These sensors measure the steering wheel's angle to determine the driver's intended direction for the vehicle.

Figure V.15.Steering Angle Sensors for BMW 3 E46

- **The ESP Control Unit**

The ESP Control Module analyzes data from the sensors and determines when to intervene to stabilize the vehicle in case of a skid. This is the central processing unit of the Electronic Stability Program, and it makes all the crucial decisions.

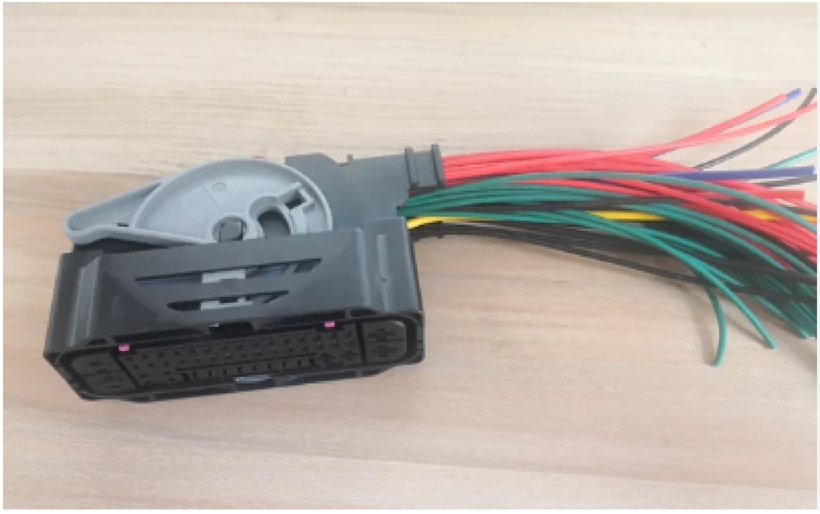


Figure V.16. ESP sensors control unit

- **Braking Actuators**

These actuators are used to selectively apply the brake to one or more wheels based on instructions from the ESP control module.

- **Engine Control Actuators**

These actuators adjust the engine torque sent to the wheels in case of a skid, based on instructions from the ESP control module.

5.3. Operating Cycle of the Vehicle's Dynamic Stability Control System (ESP)

The operating cycle of a vehicle's Electronic Stability Control system, often called ESP (Electronic Stability Program) or VDC (Vehicle Dynamics Control), generally follows these steps:

5.3.1. Real-Time Monitoring

Sensors continuously monitor key data points:

- **Wheel speed** (using ABS sensors)
- **Steering Wheel angle**
- **Yaw rate** (using a gyroscope)
- **Lateral acceleration** (using an accelerometer)

- **Accelerator pedal position**

5.3.2. Instability Detection (Ski ding)

The ESP system uses these sensors to continuously monitor the vehicle's dynamic behavior. The central control unit compares the vehicle's actual trajectory with the desired trajectory (based on the steering wheel angle). It detects a significant discrepancy, indicating:

- **Over steer** (the rear of the vehicle is skidding out)
- **Under steer** (the front of the vehicle is sliding straight)

5.3.3. Data Analysis

The system analyzes the sensor data in real-time to detect any signs of a skid or loss of vehicle control. The algorithm analyzes the discrepancy and decides whether intervention is needed. It determines which wheels to brake and whether to slow down the engine.

5.3.4. Automatic Trajectory Correction

If a skid is detected, the ESP intervenes by selectively applying the brake to one or more wheels and/or adjusting the engine torque to stabilize the vehicle and correct its trajectory. This in volves:

- **Selective braking** of one or more wheels (via hydraulic actuators).
- **Reducing engine torque** if necessary.
- **Trajectory correction:** The vehicle is brought back to the desired path.

5.3.5. Return to Normal State

Once stability is restored, the interventions stop. The system returns to passive monitoring mode, ready to intervene again.

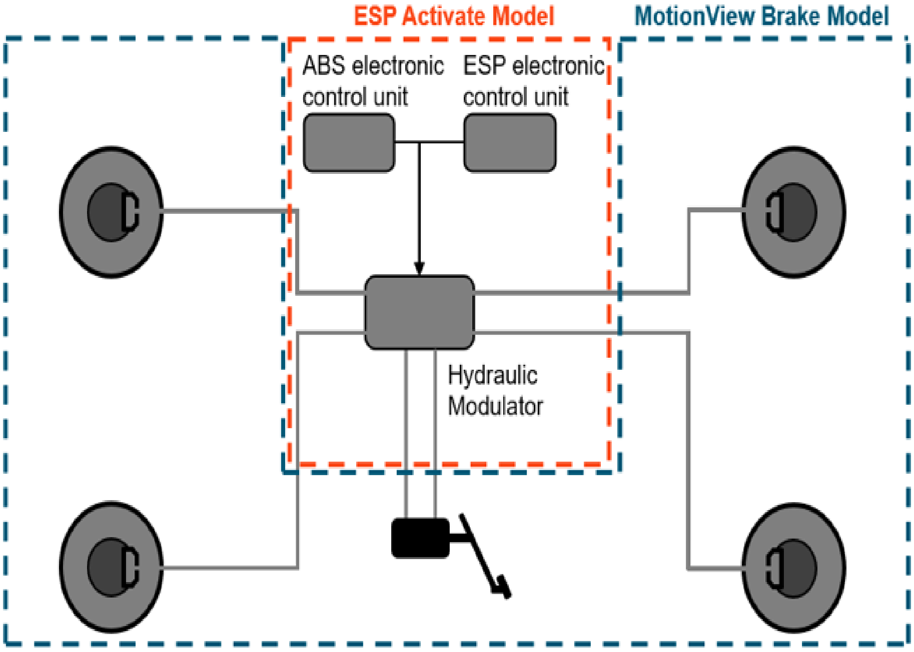


Figure V.17.Vehicle Dynamics control elements (ESP)

6. Measurement of wheel rotation speed (encoder) and vehicle speed (Doppler Effect)

Measuring wheel rotation speed with an encoder and measuring vehicle speed with the Doppler effect are important techniques used in automobiles to monitor vehicle speed and control different systems. Some of their non-exhaustive applications in the automotive sector include:

- Measuring wheel rotational speed for ABS, ESP, and traction control systems.
- Calculating distance traveled and vehicle speed for navigation and dashboard information systems.

Each technique has its own advantages, applications, and limitations, and the choice between them depends on the specific needs of the system in which they are used.

6.1. Measuring Wheel Rotation Speed (Encoder)

An encoder, specifically an incremental encoder, is used to measure the rotational speed of a shaft or a motor. It provides electrical signals that indicate angular position and, consequently, rotational speed. Incremental encoders are commonly used in various industrial applications for motion control tasks.

The principle of measuring the rotational speed of a car's wheels using an encoder is based on detecting the pulses generated by the wheel's movement.

Figure V.18.Wheel Rotation Speed (Encoder)

Key Components of Encoder-Based Measurement

- **Encoder Disk:** A disk with perforations or markings that rotates with the shaft whose speed needs to be measured.
- **Encoder Sensor:** An optical or magnetic sensor that detects the markings or perforations on the encoder disk and generates pulses based on the rotation.
- **Signal Processing Electronics:** An electronic circuit that counts the pulses generated by the encoder sensor and thus calculates the rotational speed of the shaft.

Compact and lightweight, the wheel speed sensor (**WPT**: Wheel Pulse Transducer) consists of high-resolution electronics (integrated encoder) (up to 1024ppr) in a waterproof and durable metal housing (IP67) that is placed on a vehicle's wheels. The encoder calculates the wheel's speed and angular position. Installation is quick and easy. Several sizes and configurations are available to facilitate mounting on all types of wheels.

It is used in numerous automotive applications for vehicle development, testing, and optimization. It is specifically designed for collecting measurement data such as wheel speed, vehicle speed, or acceleration. It is also used for braking tests, or to precisely calculate the vehicle's position and measure the distance traveled. It is suitable for various weather conditions (rain, snow, dust).

For a complete and precise measurement system, the **WPT** is compatible with many other electronics, rotary collectors, wheel sensors, mounting kits, adapter parts, etc.

There are two main types of encoders:

6.1.1. Incremental Encoder (Optical or Magnetic)

Incremental encoders are sensors that convert rotational movements into electrical signals. These electrical signals take the form of a pulse train, the number of which is proportional to the measured angular displacement. Counting these pulses therefore makes it possible to determine the angular position.

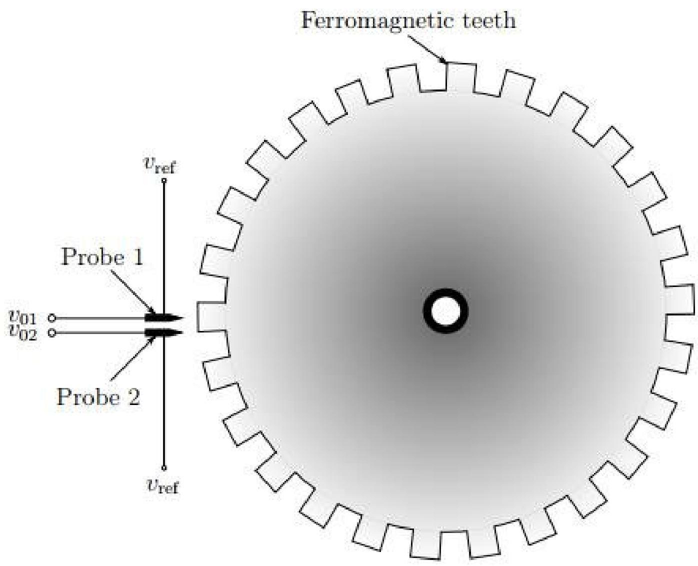


Figure V.19.Incremental Encoder

6.1.2. Absolute Encoder

Absolute encoders are sensors that convert rotational movements into electrical signals. Unlike incremental encoders, they provide a signal representing the position to be measured in the form of a binary numerical code. They have N tracks arranged according to the desired code, generally GRAY code, but also natural binary code, BCD code, or EXCESS code.

Absolute encoders provide a precise angular position, but they are less commonly used for simple speed measurement.

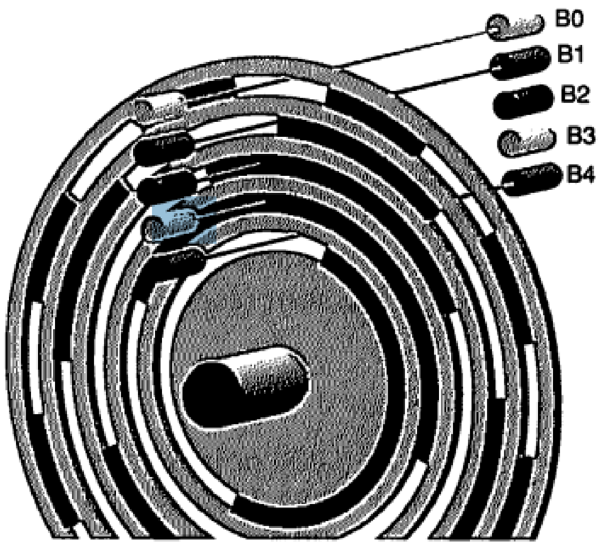


Figure V.20. Absolute encoder (Principle of coding on a 5-bit Gray disk)

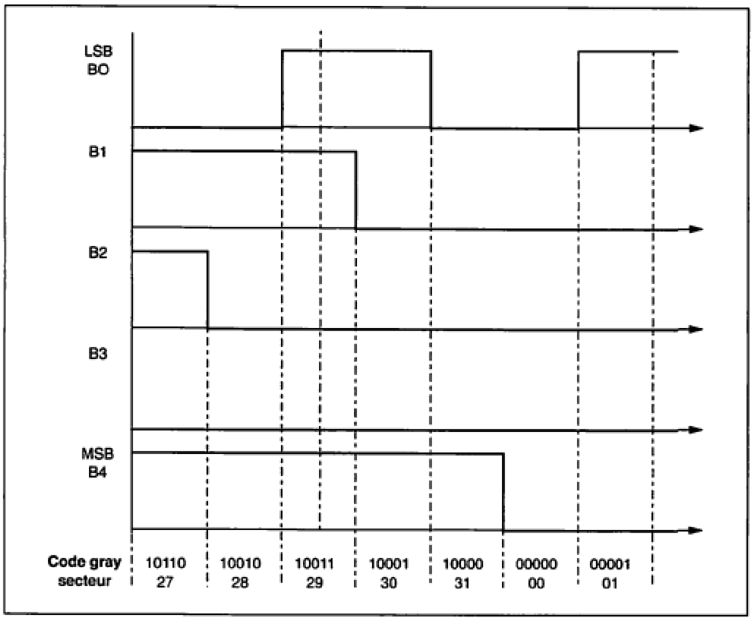


Figure V.21.Gray code corresponding to the position of the 5-bit encoder

- **Calculating Rotational Speed**

Speed is determined by measuring:

- The frequency of the pulses (number of pulses per second)
- The period (time between two pulses).

The basic formula for calculating rotational speed based on the period is:

$$\text{Speed (rpm)} = \frac{\text{Pulse number}}{\text{Time between pulse}} \times 60$$

If the encoder has N teeth/pulse per revolution, and the measured frequency is f (Hz), then:

$$\text{Speed} = \left(\frac{f}{N}\right) \times 60$$

6.2. Measuring Vehicle Speed via the Doppler Effect

- The Doppler effect, named after Austrian physicist Christian Doppler who described this phenomenon in 1842, is a pervasive principle in physics that describes the change in frequency of a wave for an observer moving relative to the source of that wave. This phenomenon occurs in both sound and light waves and has many practical applications in science and technology.
- The Doppler Effect, or **Doppler Fizeau effect**, is the shift in the frequency of a wave (mechanical, acoustic, electromagnetic, or of another nature) observed between the emission and reception measurements when the distance between the emitter and the receiver varies over time.
- When measuring a vehicle's speed, radar sends a radar signal toward the moving vehicle, and the frequency of the reflected signal is altered according to the vehicle's speed. This frequency variation is used to calculate the vehicle's speed.

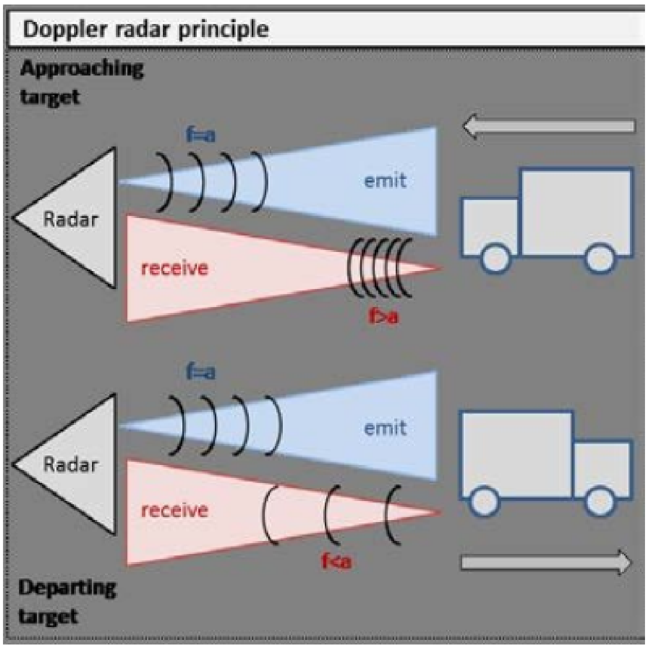


Figure V.22. Principle of Doppler radar

Key Components for Doppler Effect Measurement:

- **Doppler radar**

  A transmitter receiver device that emits a radar signal and measures the frequency of the reflected signal

- **Signal Processing Electronics**

  An electronic circuit that analyzes the frequency variation of the reflected signal and calculates the vehicle's speed

How Doppler Effect Speed Measurement Works

- **Wave Emission**

  The radar emits electromagnetic waves (microwaves in the case of traffic radars) toward the target vehicle.

- **Wave Reflection**

  The waves strike the vehicle and are reflected back to the radar.

- **Frequency Shift**

  Due to the Doppler effect, the frequency of the reflected waves is different from the emitted frequency. If the vehicle is moving away, the perceived frequency decreases; if it's approaching, the perceived frequency increases.

- **Speed Calculation**

  The radar measures the frequency difference between the emitted and reflected waves and uses this difference to calculate the vehicle's speed.

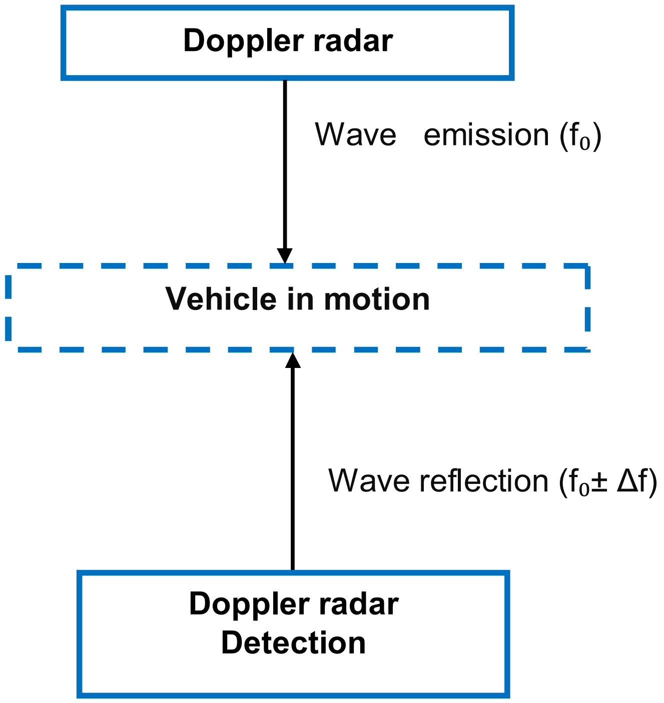


Figure V.23.Principle of the Doppler effect for measuring the speed of a vehicle

- **Formula for Calculating Speed Using the Doppler Effect**

The formula for calculating speed using the Doppler effect is derived from the relationship between the shift in frequency and the relative velocity between the source and the observer.

The fundamental formula is:

$$v = \frac{c \cdot \Delta f}{2 f_0}$$

Where:

- V: is the velocity of the target vehicle.

- Δf: Δf is the Doppler shift, or the difference between the received frequency and the emitted frequency ($f_r - f_e$).
- f_0 Is the emitted frequency of the radar signal
- ***C***: is the speed of light in a vacuum, which is approximately 3·108 m/s.

This formula is valid for scenarios where the emitted waves are reflected back to the source, like a radar gun measuring a vehicle's speed. The factor of 2 in the denominator accounts for the two-way travel of the radar signal (from the radar to the target and back).

If the radar is tilted $(angle\ \ \theta)$

$$v = \frac{c \cdot \Delta f}{2 f_0 Cos\theta}$$

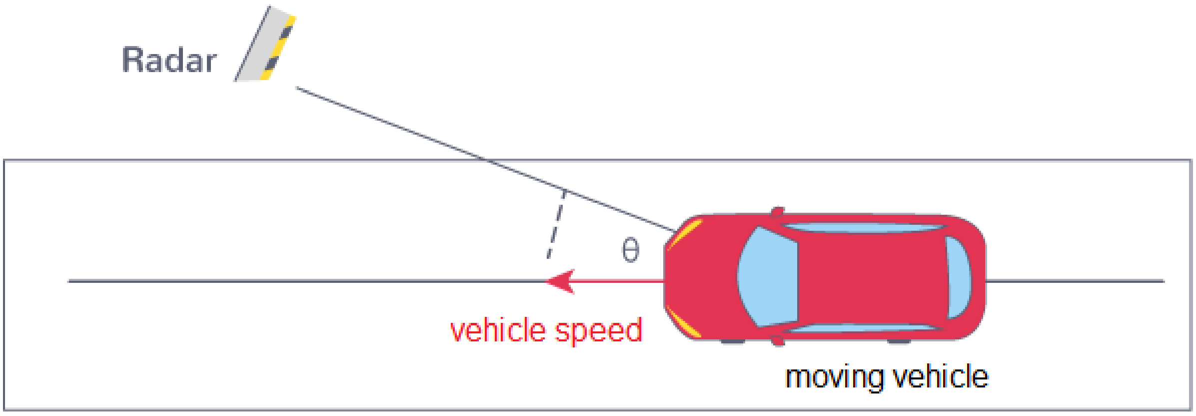


Figure V.24. Doppler effect principle for inclined radar

- ***Practical Exemple***

  A radar emits at **24 GHz** and measures a Doppler shift (Δf) of **3.2 kHz**.

  We can calculate the speed (v) using the Doppler effect formula:

$$v = \frac{\Delta f}{f_0} \cdot \frac{c}{2}$$

Given:

- $\Delta f = 3.2\ \text{kHz} = 3200\ \text{Hz}$
- $f_0 = 24\ \text{GHz} = 24 \cdot 10^9\ \text{Hz}$
- $c \approx 3 \cdot 10^8\ \text{m/s}$

Substitute the values into the formula:

$$v = \frac{3200}{24 \cdot 10^9} \cdot \frac{3 \cdot 10^8}{2}$$

$$v = \frac{3.2 \cdot 10^3}{24 \cdot 10^9} \cdot \frac{3 \cdot 10^8}{2}$$

$$v = \frac{3.2 \cdot 3 \cdot 10^{11}}{24 \cdot 10^9 \cdot 2}$$

$$v = \frac{9.6 \cdot 10^{11}}{48 \cdot 10^9}$$

$$v = 0.2 \cdot 10^2$$

$$v = 20 \text{ m/s}$$

To convert this to km/h, we multiply by 3.6:

$$20\ m/s \times 3.6 = 72\ km/h$$

The calculated speed is **20 m/s** or **72 km/h.**

7. Conclusion

Embedded systems play a fundamental role in the modern automotive industry, transforming vehicles into intelligent, connected, and secure platforms. Thanks to high-performance electronic control units, sophisticated sensors, and specialized software, these systems optimize engine performance, enhance safety (with ABS, ESP, airbags, etc.), and provide an enriched user experience (infotainment, autonomous driving).

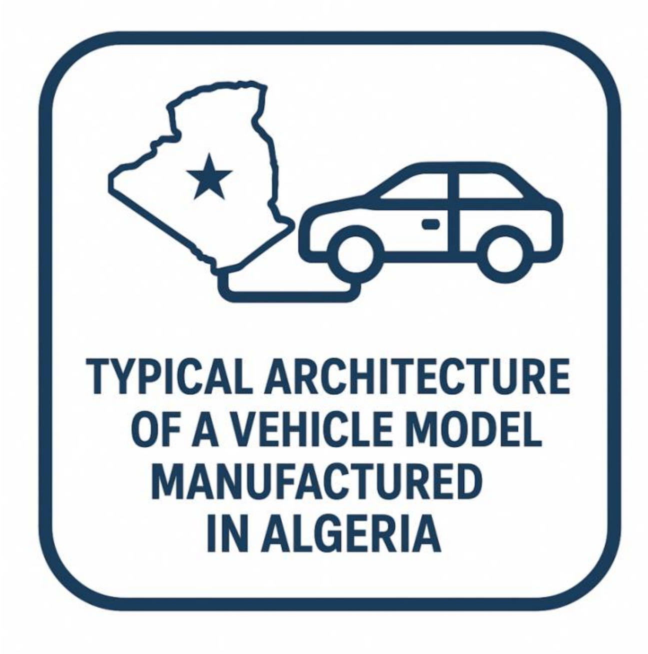
The shift towards electric and autonomous vehicles further increases the importance of embedded systems, which must manage growing volumes of data in real-time while ensuring absolute reliability. However, this complexity presents challenges, particularly in terms of cyber security, energy consumption, and the standardization of architectures.

Embedded Systems are at the heart of the automotive digital revolution, paving the way for safer, more efficient, and more sustainable mobility, their continuous development, coupled with advances in artificial intelligence and connectivity, promises major innovations for the vehicles of tomorrow.

Chapter VI

Typical architecture of a vehicle model manufactured in Algeria

Understand the technical and organizational structure of vehicles assembled or manufactured locally in Algeria, by analyzing their key components, their design adapted to the Algerian market, and their integration into the national industrial ecosystem (e.g.: Logan, Symbol of Renault Algeria) and Identify local specificities.



1. Introduction

Algeria has been developing a local automotive industry for several years, primarily based on vehicle assembly in partnership with international manufacturers (Renault, Fiat, Hyundai, etc.). This chapter will detail the technical architecture of a common model (Renault Symbol), focusing on its electronic platform (origin, adaptations) across three parts: power train, safety, and comfort.

The technical architecture of vehicles manufactured in Algeria, within the context of local production, refers to all the technical choices and construction processes implemented for the production of cars on Algerian soil. This includes the design of the chassis, bodywork, suspension systems, and electronics, as well as the manufacturing and assembly stages. The goal is to develop a local industrial base with a portion of locally produced components and the progressive integration of Algerian technology and expertise.

The Algerian automotive industry is primarily based on vehicle assembly in partnership with foreign manufacturers (Renault, Hyundai, etc.). This chapter details the technical architecture of locally produced models, with an emphasis on technological choices, local adaptations, and market constraints.

Figure VI.1. Oran factory (installation of the bodywork and paint shop completed)

Starting in 2015, the installed production capacity increased from 25.000 to 35.000 vehicles / year with the integration of a second team and an increase in the production rate from 7 to 10 vehicles / hour

In June 2016, a third manufacturing team became operational, raising the installed production capacity to 50.000 vehicles / year and creating over 700 direct jobs, which is more than double what was originally planned in the initial project.

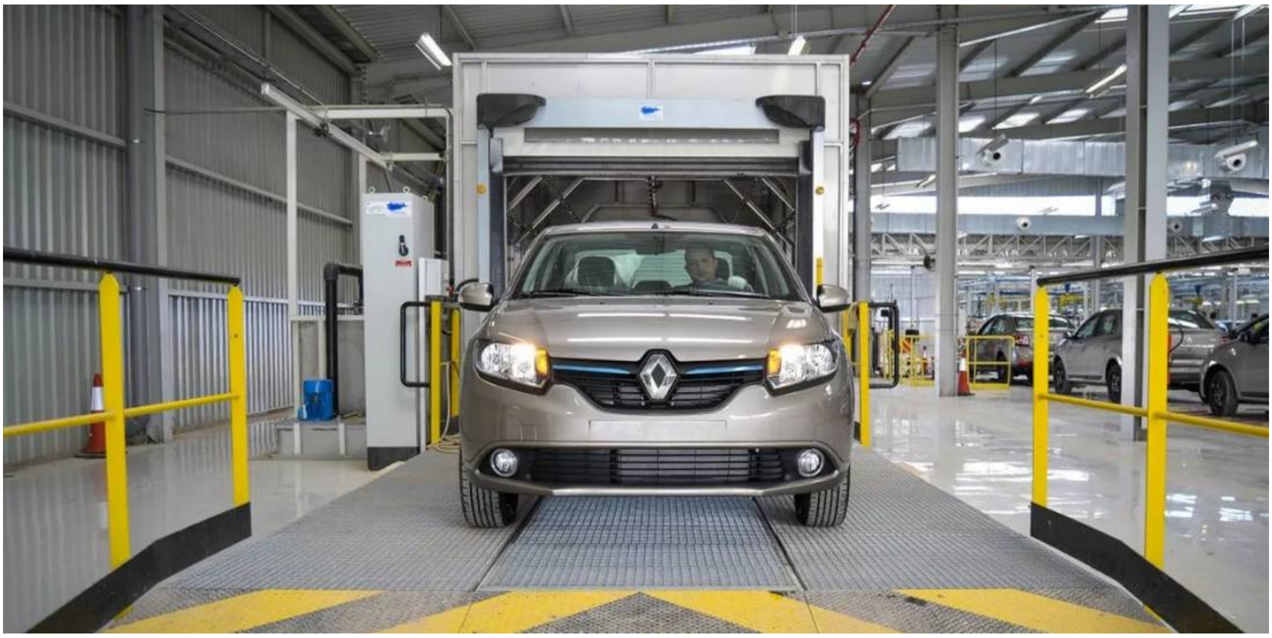


Figure VI.2. Creation of the Renault Algeria Production factory (2014)

Figure VI.3.ORAN - The factory of the Italian brand "Fiat"

This structural project was completed in record time, considering that the construction work began in November 2022, following the signing of a framework agreement in

October 2022 between the Ministry of Industry and the "Stellantis" group, the world's fourth-largest automotive manufacturer, which includes 12 brands, including "Fiat"

- **Baic D20**

The BAIC factory unveiled its product lineup, including the **Baic D20**, with a 1.3L gasoline engine and 108 horsepower, considered the cheapest car in Algeria, as it will be marketed at a price of 125 million centimes.

Figure VI.4. Batna plant - Baic D20

Additionally, the Baic factory in Batna plans to produce four other models:

- ✓ The **Baic X25** will be available in the Comfort version with a 1.5L gasoline engine and 114 hp for 1,750,000 DA. The Comfort version with an automatic transmission will be priced at 1,900,000 DA, while the Elite version with an automatic transmission will sell for 1,999,900 DA.
- ✓ The **Baic X35**, featuring a 1.5L engine with 114 hp, will be priced at 2,390,000 DA.
- ✓ The **BJ40** with a 2.0L engine and 190 hp will be priced at 4,800,000 DA for the Comfort version with a manual transmission, and 5,400,000 DA for the automatic version.

- ✓ Finally, the BAIC **PICK UP** will be sold with a 2.5L turbo-diesel engine and 174 hp for 3,400,000 DA in the 2x4 version and 3,600,000 DA in the 4x4 version.

Note: *For information purposes only, the prices mentioned are those announced by the manufacturer at the time of production and are not updated, the prices of cars produced are given for information purposes only and not as a reference.*

2. Key dates

- **2013:** On January 31, the company "Renault Algérie Production" was created. Construction on the Oued Tleilat site (near Oran) began in September.
- **2014:** The factory was inaugurated on November 10, and the manufacturing of the Symbol model began.
- **2015:** A second manufacturing team was started.
- **2016:** Assembly of the Sandero Stepway was launched, and a third team was started.
- **2017:** A subcontracting agreement was signed with over 200 local and international suppliers. The 100,000th vehicle was produced. The local integration rate was 6.5%, instead of the 20% contractually planned.
- **2018:** Assembly of the Clio 4 was launched.
- **2019:** The local integration rate dropped to 4.7% instead of the promised minimum of 30%. Renault received a first warning for not respecting contractual clauses.
- **2020:** On January 17, the factory was closed pending new regulations for the automotive industry. Algeria ended the preferential tax system for importing SKD/CKD kits for Renault vehicle assembly and demanded a minimum integration rate of 30%. On February 26, Renault put its 1,200 employees on technical leave. In August, Renault initiated a plan for 800 voluntary departures.
- **2021:** Renault announced that it would do everything possible to comply with the contractual specifications and, in May, obtained the release of a stock of kits held up at the port of Oran. 280 workers were employed for 4 months out of the 1,200 who were there before 2020. After assembling these kits, production was once again blocked.

- **2022:** The factory claimed to be carrying out work to comply with the conditions set by the Algerian government, particularly the 30% integration rate requirement.
- **2023:** A first application for approval to resume production was submitted in September but was rejected.
- **2024:** The factory remained shut down, while the neighboring Citroën plant received approval to resume production.
- **2025:** A second application for approval submitted in May 2025 was rejected. According to the Minister of Industry, Renault Algérie "never achieved a 5% integration rate" in 2019, despite "committing in 2014 to ensure a 30% integration rate in CKD assembly after five years of operation." The factory remains closed. Algeria now refuses to approve factories that are merely "tire inflators."

3. Design and Engineering

Vehicle design involves technical studies, 3D chassis drawing, body design, and the integration of various systems (engine, transmission, electronics, etc.).

Automotive design requires a multidisciplinary approach, combining mechanics, electronics, and innovation. In Algeria, the development of this sector depends on:

- Strengthening technical skills.
- Investing in R&D and infrastructure.
- Adapting to international standards and new technologies.

With a targeted strategy, Algeria could advance in the automotive value chain, particularly in niche areas like electric and industrial vehicles. Automotive design and engineering encompass several technical disciplines to develop safe, high-performance, and economical vehicles.

Here are the essential basics of this field:

- **Market Study & Specifications:** Defining the needs (vehicle type, performance, cost, regulations) and analyzing the competition and trends (electrification, connectivity).
- **Design & Styling:** Exterior/interior design (aerodynamics, ergonomics, aesthetics) and physical and virtual models (using tools like Alias, Photoshop, Blender).
- **Mechanical Engineering:** Chassis and body (strength, lightweight materials like steel, aluminum, composites); Power train (choice of type - combustion, electric, hybrid); Transmission (gearbox, front-wheel/rear-wheel drive); Suspension & Braking (comfort and safety).

- **Simulation & Validation:** CAD (CATIA, SolidWorks, AutoCAD for precise 3D modeling); FEM calculations (ANSYS, Abaqus) through virtual strength and crash tests; Computational Fluid Dynamics (CFD) for aerodynamics (e.g., STAR-CCM+ software).
- **Prototyping & Testing:** Fabrication of prototypes (3D printing, machining); Wind tunnel, track, and real-world condition testing.
- **Industrialization:** Production planning (robotics, assembly line); Cost and logistics optimization.

Automotive design and engineering in Algeria are in a developmental phase, with promising projects but also structural challenges.

4. Chassis and Structure

The chassis is the main structure of a car, and all other components, including the engine, transmission, suspension, and body, are mounted on it. It serves as the vehicle's skeleton, ensuring the cohesion of the whole and its ability to function correctly.

The chassis, often made of steel, forms the basic structure of the vehicle. It must be designed to ensure rigidity, safety, and durability.

Figure VI.5.Automotive chassis

The car chassis is the backbone of any vehicle. While it's often unknown to the general public, it plays a fundamental role in a car's handling, safety, comfort, and performance. In this article, we'll break down what a car chassis is, its different types, its components, and its crucial importance in the design of modern vehicles.

The chassis plays several essential roles:

- It supports the weight of the vehicle and its passengers.
- It absorbs shocks and vibrations from the road.
- It ensures directional stability and handling.
- It protects occupants in case of a collision.
- It serves as the assembly base for all mechanical components.

The chassis includes several essential elements:

- ✓ **Side members:** The main longitudinal parts.
- ✓ **Cross members:** These provide the transverse connection.
- ✓ **Suspensions**: These absorb road irregularities.
- ✓ **Steering system**: This allows for trajectory control.
- ✓ **Brakes:** These ensure safety by slowing down the vehicle.

5. Bodywork

In Algeria, the automotive bodywork industry includes the repair, painting, and restoration of vehicle bodies. There are workshops specializing in multi-brand repair, body protection, and restoration, such as Autoqual, which claims to be the country's largest workshop. The sector also involves the manufacturing of bodywork for different types of vehicles, including trucks, buses, and special-purpose vehicles.

The body can be made of metal, composite materials, or a combination of both. It must be designed for aerodynamics, aesthetics, and occupant protection.

Some workshops use advanced equipment and train their staff to international standards. Autoqual, for example, works with companies that have vehicle fleets and collaborates with insurance companies. Algeria has specialized companies that manufacture bodywork for various vehicles, including trucks, buses, refrigerated vehicles, and medical vehicles.

Figure VI.6. Car bodywork

6. Electronic and electrical circuit

Embedded electronics play an increasing role in managing the engine, safety systems, comfort, and infotainment.

Complete and detailed wiring diagrams for the Renault Symbol (manufacturer's plans) are protected by Renault's copyrights and safety regulations. Therefore, we can provide an educational diagram that shows the main circuits: the engine power circuit (battery, alternator, starter, ECU), the lighting system (headlights, taillights, switches), the comfort system (UCH, power windows, central locking), etc.
We can represent this diagram in a clear format.

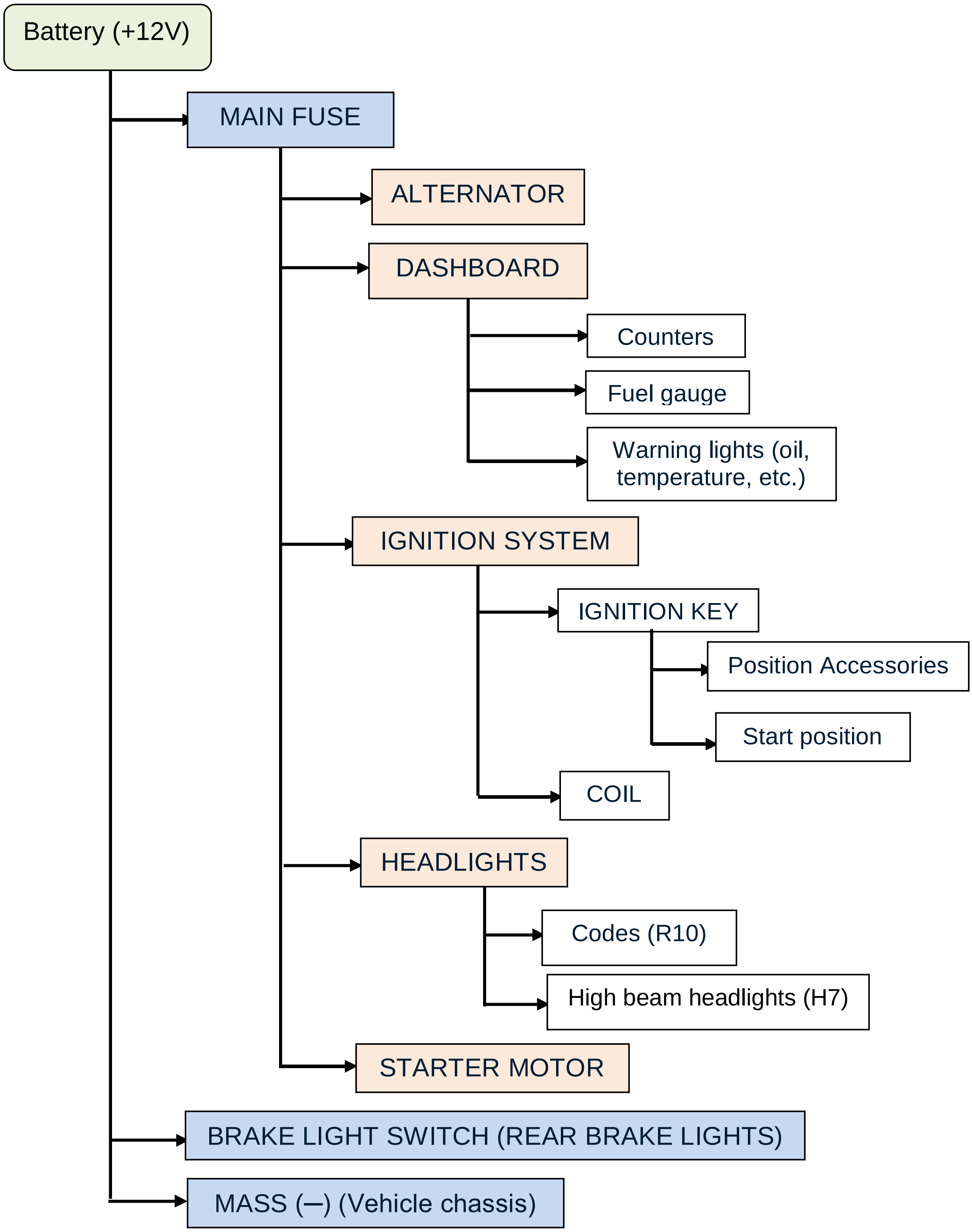


Figure VI.7. Simplified electrical diagram of Renault automobile

This section provides an overview of the electronic architecture of Renault vehicles produced or assembled in Algeria. We will cover the main electronic control units (ECUs), on-board communication networks (CAN, LIN, FlexRay), sensors, and actuators. We will also present a technical and operational summary of the electronics, diagnostic and maintenance procedures, and the specific implications of local assembly.

Renault vehicles produced locally in Algeria (such as the Renault Symbol, Logan, and Sandero) generally follow Renault's technical specifications, but with some adaptations for the local market.

6.1. Engine Management System (ECU - Engine Control Unit)

This system controls electronic injection, ignition, and engine performance. It is adapted to the climatic conditions and fuel quality in Algeria.

6.2. Electrical Circuits and Wiring

The wiring is designed to withstand temperature variations (intense heat in certain regions). Some models may have simplified electronic options to reduce costs.

6.3. Charging System and Battery

The battery is reinforced to handle high temperatures, and the alternator is adapted for frequent urban use (stop-and-go traffic).

6.4. Lighting and Signaling

Headlights and taillights comply with local standards. Certain models may not include LED or automatic lights, depending on the trim level.

6.5. Safety Systems and Airbags

Depending on the version, the vehicle may have **ABS** and airbags (mandatory on some models). It also includes shock sensors and a central locking system.

6.6. Connectivity and Infotainment

Based on the trim level, options may include an FM radio, Bluetooth, and sometimes a touch screen (in high-end versions). It also features a USB port and smart phone compatibility.

6.7. Electronic Diagnostics (OBD)

An **OBD-II** port is included for diagnosing faults, conforming to international standards.

Renault vehicles in Algeria may have differences compared to European models, particularly in their electronic options, to suit the local market and cost considerations. The Algerian **Renault Symbol** is a reliable car, but its electronics are simplified compared to European models to reduce costs. Its electrical system is adapted to local conditions but requires regular maintenance of the battery, alternator, and electrical contacts.

7. Case Study: Renault Symbol (Algerian Version)

The Renault Symbol, produced in Algeria from 2014 to 2022, is a good case study for understanding how a global automotive platform is adapted for a local market. Derived from the Dacia Logan II, it leverages the same **B0+ platform** from the Renault-Dacia group, but its electronic architecture is specifically tailored to meet the needs and constraints of the Algerian market.

7.1. Key Aspects of the Electronic Architecture for Algeria

The study of the Renault Symbol's on-board electronics in Algeria highlights a balance between incorporating modern systems and adapting to local conditions, including cost considerations and environmental factors.

7.2. Main Electronic Systems and Their Roles

The vehicle's electronic systems are crucial for safety, performance, and comfort. Here is a breakdown of their functions in the Algerian Symbol:

- **Engine Control Unit (ECU):** This is the core of the engine management system. It's programmed to manage the electronic injection and ignition, optimizing engine performance for local conditions, such as adapting to the quality of available fuel and handling the intense heat in certain regions.
- **On-board Communication Networks (CAN, LIN):** These networks allow the different ECUs to "talk" to each other, sharing data to ensure all systems work together seamlessly. While more complex networks like FlexRay are used in high-end vehicles, the CAN and LIN protocols are sufficient for the Symbol's needs and help keep costs down.
- **Sensors and Actuators:** A network of sensors (e.g., for speed, temperature, and pressure) provides data to the ECUs, which then send commands to actuators (e.g., fuel injectors, throttle body, and ABS solenoids) to control the vehicle's functions.

7.3. Local Adaptations for the Algerian Market

The main difference between the Algerian-assembled Symbol and its European counterparts lies in the strategic simplification of its electronics to make it more accessible and better suited for the local environment.

- **Cost Reduction:** To keep the final price competitive, certain high-end electronic features, such as automated lights, rain-sensing wipers, and advanced driver-assistance systems (ADAS), may not be included in all trim levels. The focus is on essential features that offer the best value.

- **Climate-Specific Components:** The vehicle is equipped with a **reinforced battery** to withstand high temperatures and an **alternator** designed for frequent stop-and-go driving, which is common in urban areas.
- **Maintenance and Diagnostics:** The vehicle includes a standard **OBD-II port**, making it compatible with international diagnostic tools for efficient maintenance and troubleshooting. This is a crucial feature for local garages.
- **Special Features:** One notable feature of the Algerian Symbol is the inclusion of a **GPS navigation system** in some versions, making it one of the first locally produced vehicles in Algeria to offer this technology.

Overall, the electronic architecture of the Renault Symbol in Algeria is a case study of smart engineering and localization. It demonstrates how a global automotive platform can be modified to meet the specific economic, environmental, and operational requirements of a particular market.

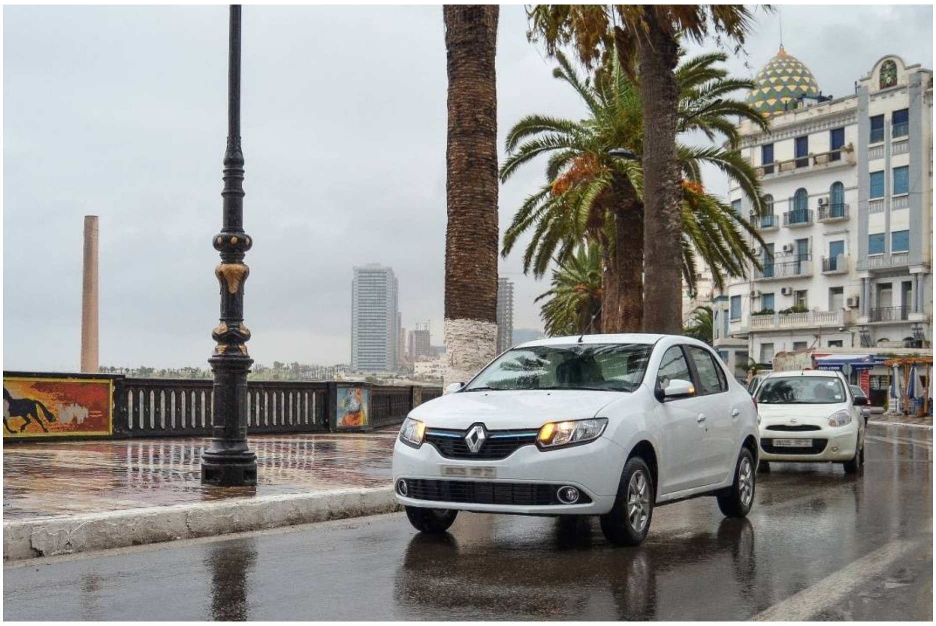


Figure VI.8. Algerian Renault Symbol (Oran)

7.4. Local Context

This section provides an overview of the local context for the Renault Symbol in Algeria, highlighting key factors that influenced its design and features.

- **Local Assembly:** The vehicles were locally assembled from **CKD (Completely Knocked Down)** kits at the Renault Algérie Production plant in Oran.
- **Engines:** The available engines were the **1.2-liter 75 hp** and the **1.6-liter 80 hp MPI gasoline engines**.
- **Target Audience:** The vehicle was aimed at families, taxi drivers, and small businesses, which required a reliable and cost-effective solution.
- **Constraints:** Several constraints shaped the vehicle's final specifications:
    - ✓ **Hot Climates:** The electronics and mechanical systems needed **adapted thermal management** to handle intense heat.
    - ✓ **Variable Fuel Quality:** The **ECU (Engine Control Unit)** had to be specifically calibrated to handle the varying quality of fuel available in the country.
    - ✓ **Reduced Cost:** To keep the vehicle affordable, certain **electronic assistance features** found on European Symbol models were omitted.

7.5. Overall electronic architecture

The Algerian Symbol uses a simple multiplexed CAN (Controller Area Network) with a speed of 500 kbit/s for the powertrain and 125 kbit/s for the comfort systems.

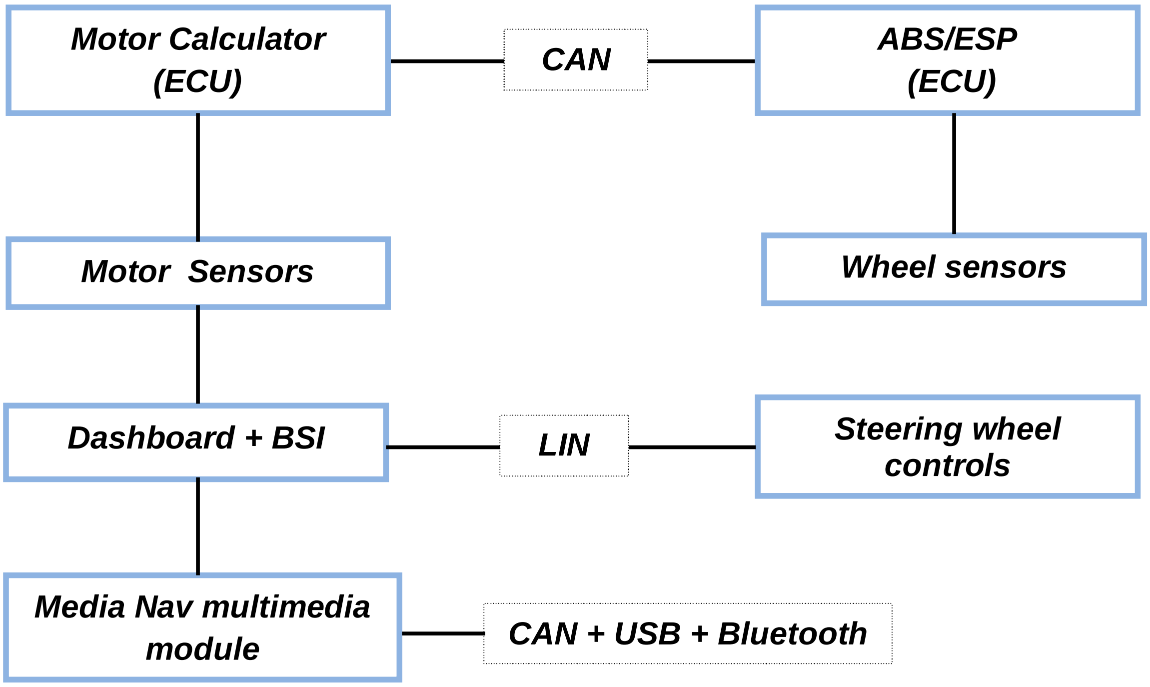


Figure VI.9. Simplified block diagram

7.6. Principal Electronic Systems

7.6.1. Engine Control Unit (ECU)

- **Type:** Bosch ME17.9.21 (gasoline).
- **Functions**

  Manages sequential multipoint injection, controls ignition, and performs OBD-II diagnostics (via the DLC port under the dashboard). It also adapts to the local octane rating.
- **Key Sensors**

  This system relies on a number of key sensors to function correctly, including the Crankshaft Position Sensor (CKP), Camshaft Position Sensor (CMP), Lambda sensor, Coolant Temperature Sensor, MAP (Manifold Absolute Pressure) Sensor, and Knock sensor.

Figure VI.10. Calculator of an Algerian Renault Symbol vehicle

The Engine Control Unit (ECU) is the on-board computer that manages the engine in real-time. It controls everything from fuel injection and ignition to turbo pressure, idle speed, and emissions. The ECU constantly adapts its settings based on data from various sensors, including those for temperature, pressure, airflow, throttle position, and lambda probes. It also centralizes diagnostic functions, storing error codes and communicating with other control units via the CAN bus.

- **Physical Characteristics and Location**

  Renault ECUs are typically housed in a metal casing that acts as a heat sink, with one or more plastic connectors on the side. The casing usually has a manufacturer's label with reference numbers.

- **Typical Location on a Renault Symbol**

  The ECU's location can vary depending on the model year and engine type. It's often found in the engine compartment, near the battery or firewall, or sometimes under the dashboard trim. On many Renault Logan/Symbol models, you'll find it either in the passenger compartment, near the engine side, or directly in the engine bay.

- **Connectors and Diagnostics**

  The ECU receives signals from dozens of sensors and sends commands to components like injectors, ignition coils, the EGR valve (if present), and pressure sensors. It is accessible for diagnostics through the OBD port, which allows a technician with a diagnostic tool to read and clear fault codes and measure real-time parameters.

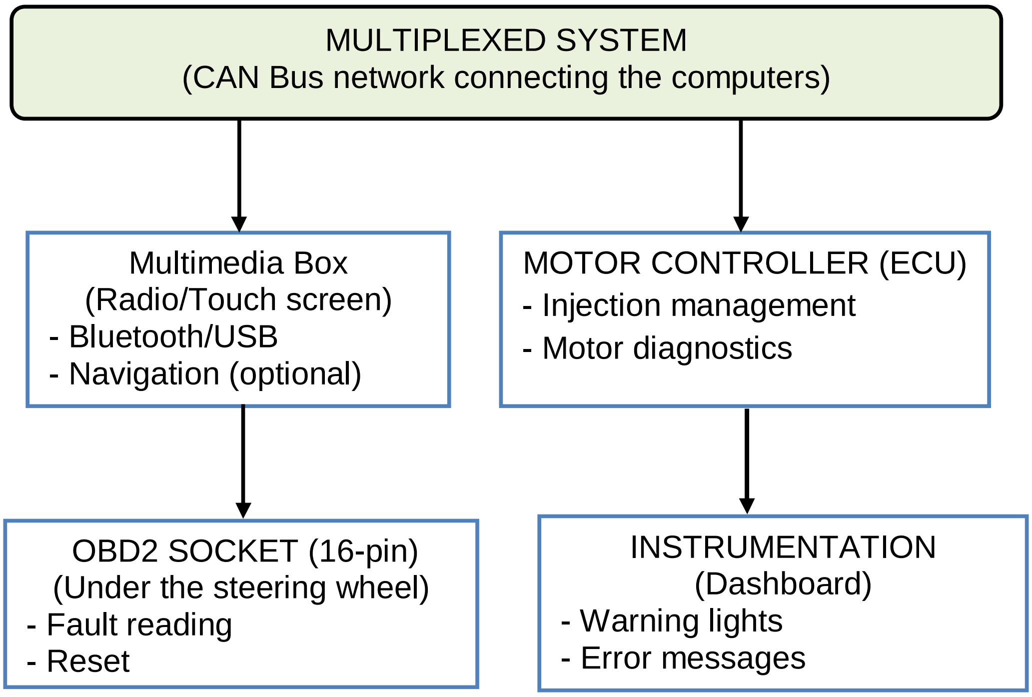


Figure VI.11.Connectivity and Diagnostic System – Renault Symbol Algeria

- **ECU Replacement, Reprogramming, and Repair**

Replacement and Reprogramming: When an ECU needs to be replaced, it often requires programming, cloning, or "virginizing." This process adapts the unit to the specific vehicle, especially for the immobilizer and anti-start systems. Specialists offer remapping services to optimize performance or provide standard replacement units.

Repair: For repairs, the ECU is typically sent to a specialized workshop. Technicians will dismantle the unit, perform electronic checks, and reflash the software if necessary.

- **Precautions Before Handling**

Working with an ECU requires great care to avoid causing permanent damage. Here are the key precautions to take:

  - **Disconnect Power:** Always turn off the ignition and disconnect the car battery before touching the ECU.
  - **Prevent Static Discharge:** Take precautions to avoid **electrostatic discharge**, which can damage sensitive electronic components.
  - **Do Not Open the Case:** Never open the ECU's casing yourself unless you are a trained professional.

- **Note References:** Before removal, always note the ECU's reference numbers.
- **Proper Handling:** Improper connection or intervention can permanently damage the unit.

7.6.2. ABS System (and ESP depending on version)

- **ABS/ESP Module:** Continental MK60E.
- **Sensors:** Wheel speed sensors on all 4 wheels (**Hall effect**), pressure sensor in the master cylinder, and a longitudinal acceleration sensor (**ESP**).
- **Actuators:** Hydraulic solenoid valves (for pressure modulation) and a recirculation pump.
- **Specifics for the Renault Symbol:**
  - On some versions (Symbol 2 or Logan), the ABS is provided by **Bosch 8.0** or a similar system.
  - It can be combined with **ESP/ASR** on higher-end versions.
  - The front sensors are often integrated into the wheel bearing, while the rear ones can be separate.

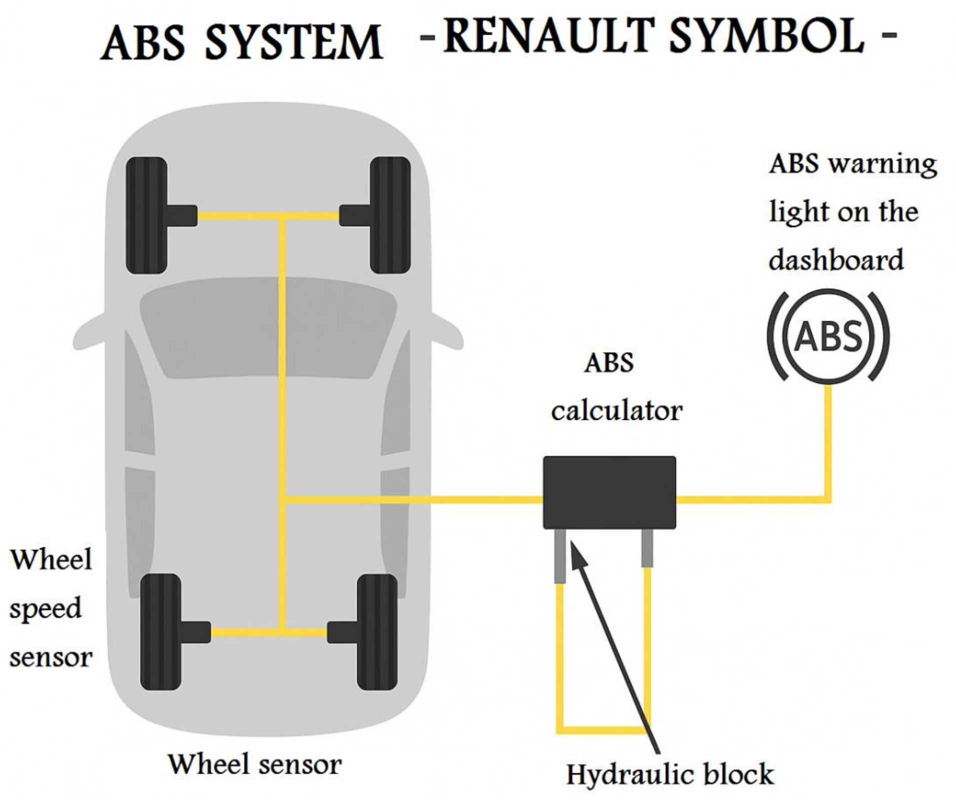


Figure VI.12. Simplified diagram of the Renault Symbol ABS system

There is no single, universal electronic diagram for the Renault Symbol ABS system, as diagrams vary depending on the model year and specific vehicle equipment. However, the main components and their operation can be described.

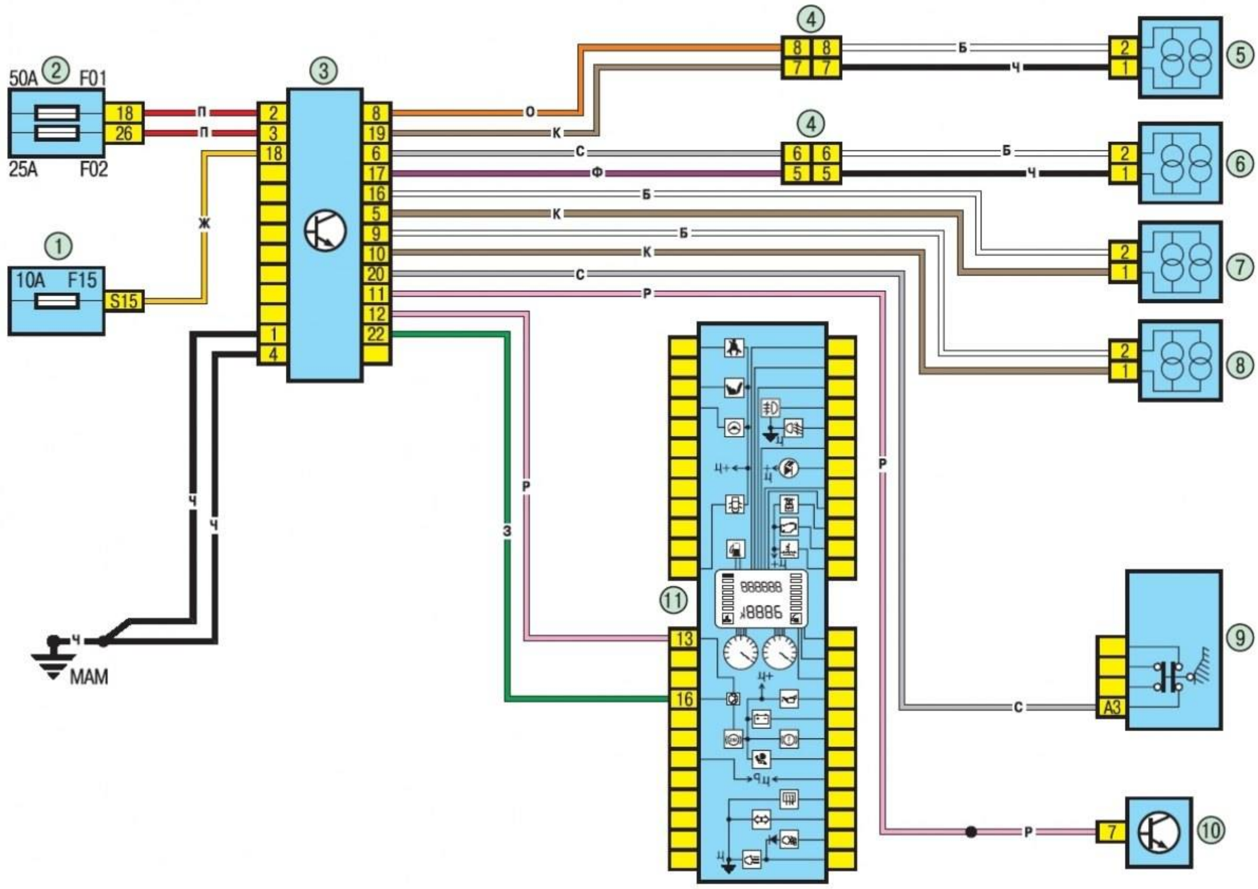


Figure VI.13.Renault Symbol ABS system electronic diagram

7.6.3. Body Control Module (UCH / BSI)

The UCH (Unité Centrale Habitacle), also known as the BSI (Boîtier de Servitude Intelligent) in some other brands, is an electronic control unit that manages most of the electrical and electronic functions not directly related to the engine. It acts as the interface between the driver's commands, comfort/safety sensors, and the actuators in the passenger compartment.

- <u>**Main Functions on a Renault Symbol**</u>

  The UCH performs several critical functions to ensure comfort and security:

  - ✓ **Lighting Management:** Controls headlights, parking lights, turn signals, and brake lights.
  - ✓ **Wiper Management:** Manages both front and rear wipers and the windshield washer.

- ✓ **Central Locking:** Handles the remote locking and unlocking of the doors.
- ✓ **Anti-theft Alarm & Immobilizer:** Manages the vehicle's security systems.
- ✓ **Power Windows:** Controls the raising and lowering of the electric windows.
- ✓ **Dashboard Management:** Manages indicator lights and audible alerts.
- ✓ **CAN Bus Interface:** Acts as a gateway for communication between different control units via the multiplexed **CAN bus**.

- **<u>Typical Location</u>**

On the Renault Symbol, the UCH is typically located inside the passenger compartment, often found under the dashboard on the driver's side, near the fuse box. It is usually integrated into the vehicle's interior electrical distribution box.

- **<u>Connections to Other Systems</u>**

The UCH is a central hub that links to various other systems:

- ✓ It communicates with the Engine Control Unit (ECU) via the multiplexed CAN bus to exchange information about the immobilizer and overall vehicle status.
- ✓ It is connected to various sensors and switches, such as buttons, door contacts, and, on some models, rain and light sensors.
- ✓ It controls actuators such as relays, power window motors, and lighting relays.

Figure VI.14.Illustrated diagram of the Central Passenger Compartment Unit (Renault)

7.6.4. Dashboard

- **Type:** A combination of analog displays and a central LCD screen.
- **Electronic Functions:**
  - ✓ Displays speed, engine RPM, engine temperature, and fuel level.
  - ✓ Shows diagnostic warning lights for the **MIL (Malfunction Indicator Lamp)**, **ABS**, **Airbag**, and **oil pressure**.
  - ✓ Communicates with the engine's ECU and ABS module via the **CAN interface**.

7.6.5. Multimedia System

- **Media Nav Evolution (on Extreme versions):**
  - ✓ Features a 7-inch touchscreen.
  - ✓ Includes a GPS navigation system with maps for the Maghreb region.
  - ✓ Offers Bluetooth for hands-free calling and audio streaming.
  - ✓ Has USB and AUX ports.
- **Networks:**
  - ✓ Uses a **CAN** network for integrating vehicle information.
  - ✓ Features an internal **GPS** unit and a built-in FM/AM antenna.

7.6.6. Passive Safety Systems

The Renault Symbol, produced in Algeria, is equipped with several passive safety systems designed to protect occupants in the event of an accident. Unlike active systems (like ABS or ESP) which help prevent a crash passive safety systems work after a collision to minimize injuries.

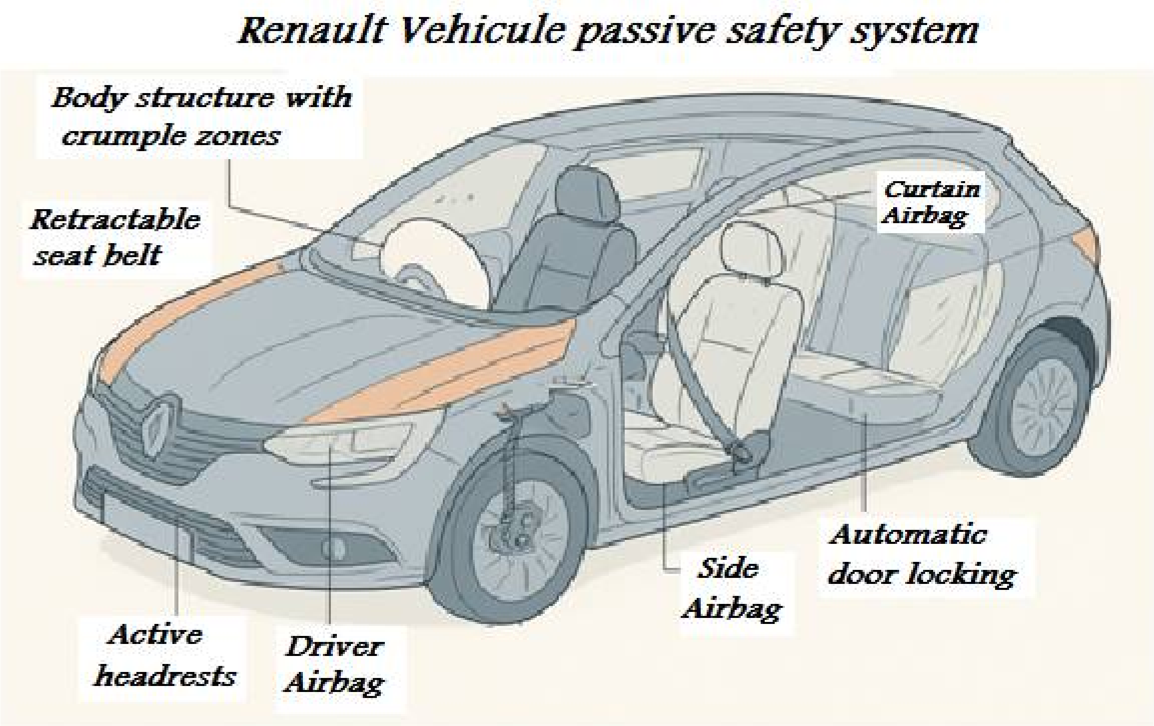


Figure VI.15.Renault vehicle passive safety system

Airbags deploy automatically during a collision. Their purpose is to cushion the impact and protect the driver and passengers with inflatable cushions. They work in conjunction with the seat belt, without which their action is ineffective. Depending on their location (on the steering wheel, on the dashboard, or in the seat), airbags can activate between 5 and 150 milliseconds.

They use two electronic modules: an airbag control unit (which detects a collision via accelerometers) and pyrotechnic deployment (via controlled igniters).

Figure VI.16.Airbag system activated (airbags)

7.6.7. Algerian Specifics

This section details the specific adaptations made to the Renault Symbol for the Algerian market, focusing on how electronics were tailored to local conditions and economic factors.

- **Electronic Module Simplification:** Some electronic modules were simplified to reduce the final price. For example, entry-level trims do not include a rear parking sensor.
- **ECU Calibration:** The **Engine Control Unit (ECU)** was calibrated to work with local SP95 and SP98 fuels and to tolerate lower-quality fuel, which is crucial for reliability in the region.
- **Multimedia System:** The **Media Nav** system was delivered with regional mapping (for the Maghreb) instead of the full European mapping found on other versions.
- **Safety Features: ABS** was often a standard feature, while **ESP** was either an option or absent on entry-level models to control costs.

7.6.8. Maintenance and Diagnostics

- **Standard OBD-II Port:** The vehicle uses a standard **OBD-II port** with the ISO 15765-4 CAN protocol, making it compatible with widely used diagnostic tools.
- **Dealership Software:** Renault dealerships in Algeria use **Renault CLIP** for manufacturer-level diagnostics and can perform ECU updates via CAN flashing.
- **Maintenance Challenges:** Electronic maintenance can be limited in independent garages due to a lack of specialized equipment.

The Algerian Renault Symbol is a perfect example of how a manufacturer adapts an existing technical platform for a specific market. It highlights a strategic balance of:

- **Maintaining Essential Features:** Keeping core electronic functions like a modern **ECU**, **ABS**, and **UCH** in place.
- **Cost-Effectiveness:** Reducing optional features to remain competitive on price.
- **Enhanced Durability:** Ensuring robustness and calibrating systems for harsh local conditions.

Despite its relative simplicity compared to its European counterparts, the Symbol played a significant role in making modern automotive electronics (such as **ABS**, multipoint **ECU**, and **CAN** multiplexing) accessible in a developing market.

8. Conclusion

The analysis of the architecture of vehicles produced in Algeria, exemplified by the Renault Symbol, reveals a design specifically adapted to the unique characteristics of the Algerian market. This adaptation is evident in several key aspects.

On one hand, manufacturers have opted to simplify technical systems, favoring proven solutions over the latest innovations. This approach is reflected in the use of less sophisticated engines compared to their European counterparts and a reduction in electronic and connected options.

On the other hand, while passive safety systems meet basic standards, they have limitations compared to models intended for European markets, particularly concerning supplementary protective equipment.

Diagnostics and maintenance systems are designed to fit local realities, being accessible but less comprehensive than those available on international versions. This architecture reflects a desire to balance technical quality with economic constraints, all while ensuring robustness suited to local climate and usage conditions.

This configuration is a testament to a pragmatic industrial strategy aimed at providing vehicles that are affordable, easy to maintain, and reliable enough to meet the expectations of Algerian consumers while maintaining a link to the manufacturer's technology. The future evolution of this architecture will depend, in particular, on the development of infrastructure and the growing expectations of users regarding connectivity and energy efficiency.

General Conclusion

This handout, designed as an educational resource for the *Embedded Systems for Automotive* module, aimed to provide students of the Master's program in "Embedded Systems Electronics" with a solid and structured foundation to grasp this rapidly evolving field.

Organized into six progressive chapters and illustrated with concrete examples, this document methodically presented the fundamental concepts, from the hardware architecture (computing units, sensors, actuators) and specific software development (real-time, functional safety) to the internal communication networks (CAN, LIN, etc.) that form the technological backbone of the modern vehicle.

This text has highlighted the fundamental transition undertaken by the automobile: from a purely mechanical machine, it has become a "system of systems," a sophisticated network of computing units in permanent communication. This revolution is driven by major trends such as electrification, connectivity, and autonomy, transforming the vehicle into a veritable software platform on wheels.

It follows that mastering these technologies is no longer a peripheral skill but the core competency for designing and producing the automobile of tomorrow. Embedded systems are its nervous system and intelligence, where the essential added value is now created.

While the challenges to overcome remain numerous – growing complexity, cyber security, managing computing power – they also outline a highly stimulating technical landscape for the engineers of tomorrow.

Finally, this document intends to be much more than a simple collection of course notes; it aspires to be a reference tool that offers a coherent and practical overview, fostering the understanding and application of the essential principles that will shape the future of mobility.

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