Modern Car Handbook

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Annotation

The handbook presents innovative technologies of a modern car. Cars with internal combustion engines are mainly overviewed. Hybrid and electric vehicles are presented as well. Great attention is paid to technologies that ensure fuel economy and reduction of gas emissions. The newest internal combustion engine technology is presented and explained. The car passengers and driver safety systems are widely considered. The assist and self-adaptive technology principles for safely ride are reviewed and discussed too. Also, an introduction in the latest technologies that help to protect the surrounding road users and particularly pedestrians is delivered. Car security issues and some recommendations to protect your car from theft are introduced. Car computers elements and its applications for car control and diagnosis are examined. Widely and in details are discussed sensor system which applies in a modern car. Sensors operation principles (physics) and technologies are studied and presented as well.

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Introduction

There are three priorities in car industry at present: fuel consumption, ecology and safety. The global total number of vehicles currently in use is about or more than one billion 1×10^9 (milliard) in the world. In 2015, the global automotive manufacturing industry all time grows and reach a volume of about 1×10^8 (100 million) units per year.

In Table 0.1 is presented passenger cars and commercial vehicles production in 2017 year for some selected countries and total worldwide. All numbers in table is in millions. Also, in table presented passenger cars and commercial vehicles in use and Motorization in 2015 year. Motorization means number of vehicles for 1000 persons. That statistics and more can be found in cited References [0.1-0.3].

Table 0.1. Number of passenger cars and commercial vehicles production in 2017 year for a few selected countries and total worldwide. All numbers in table is in millions (excluding Motorization). Also, in table presented passenger cars and commercial vehicles in use in 2015 year.

Country	Passenger cars, 2017 production	Commercial vehicles, 2017 production	Passenger cars in use, 2015	Commercial vehicles in use, 2015	Motorization, 2015
China	24.8	4.2	135.8	27	118
Japan	8.3	1.3	61.0	16.4	609
German	5.6	-	45.1	3.4	593
USA	3.0	8.2	122.3	141.9	821
All countries	73.5	23.8	947	335	182

There are now three greatest companies that produce an identical number of cars per year. The Volkswagen group which incorporates Volkswagen, Porsche, Audi, Skoda and Seat has held the title of world's largest automobile manufacturer for a some of years. Similar results show Toyota. At that positions begins change and starts new largest leading automaker: Renault-Nissan-Mitsubishi Alliance. Renault and Nissan each sell a lot of cars on their own, 3.76 million and 5.82 million worldwide in 2017. Mitsubishi sell 1.03 million cars in 2017. All Alliance Renault-Nissan-Mitsubishi achieve to 10.61 million. All of those three companies produce over 10 million cars per year [0.4, 0.5].

Our goal is to overview the modern vehicles. Maybe this information will help you to pick your own car. We do not include classical elements of vehicles in this discussion. Detail information are often found in fundamental books which list will be presented below. Our goal is to bring more attention to the elements of a modern car and to discuss and overview part of them in more detail

Safety is still one of the foremost important selling propositions in the automotive industry. That is why it makes up the bulk of investments in the field of car applications. At present Emergency Assist system, that automatically stops the car in case of an emergency, is being implemented. In the future, numerous innovations will rise to exclude human factor in accidents.

The cars coming off manufacturers production lines today are packed with more technology than many of us understand. Anti-lock braking systems, Electronic stability control, Traction control - all of these are considered standard features in most current made cars.

At present does not require switch electric lamps for lighting or adjust windows wipers from the strength of the rain. Your concerns are often more focused on safety driving a car.

Modern cars are faster, better handling, more comfortable, large capacity, well-designed interior, cleaner, safer, more economical, and may be cheaper to purchase.

Scientists, engineers and car makers are throwing huge efforts to reduce their fuel consumption and emissions. Fuel saving is both a reduction in emissions. Try another substitute for an internal combustion engine. It is often hybrid or electric cars. It seems that this will solve problems. However, it's said that we are developing a replacement problem, like recycling of batteries and chemicals.

Let us remember in advance that an internal combustion engine converts only about 30% (1/3) of the energy (fuel) that we put into a conventional vehicle into mechanical work (to drive on the road). During this stage of development, there's still a really high prospect. We don't change the laws of physics, but we will always make the best use of them. After reading or a minimum of flipping through the book you'll notice what an enormous breakthrough has been made in applying new scientific advances in car manufacturing. Yet an enormous breakthrough is achieved with the utilization of computer elements and various physical sensors. We are going to be glad that you simply can find more useful information in this book. The part of the book material is presented in table forms, which is user handily. More detailed technical information you'll find in fundamental cited books or internet pages [0.6-0.35].

In writing the handbook, we were guided by Fair use doctrine [0.36]. The main goal of the handbook is to systematize and popularize scientific knowledge and make it available to the general public in an accessible form. The handbook can also be a useful tool for college students with a technical profile.

Acknowledgments.

We are grateful to the automotive industry companies, reviews and research authors, also books authors for providing access to both print and online information. Thank you to everyone whose contribution is important to the progress of the car industry and engineering science, and whose achievements have been shared, which has enabled us to disseminate them in a compact way to a wider audience.

We grateful to our families for comprehension and patience.

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Sincerely yours, authors Benas Kundrotas and
Algis Jurgis Kundrotas

Chapter 1 Modern Car

In each historic period a modern car is described differently. For one period, modern one was a lovely car, another modern car was that which had a starter or power steering (power assisted steering). These changes happened step by step. Today's modern car is difficult to define. Maybe it is not necessary in this rapid technical progress age that we are living now, an excellent age of the cars or more precisely within the age of computers and cars.

The car is more than a vehicle. This is often an honest example of the coexistence of science and engineering thought. The development of the car industry has brought many innovations, but it also has many negative consequences. Therefore, from time to time, it is necessary to evaluate our success rates and adjust our future plans.

This chapter introduces you to the car structure and various auto parts definitions. Knowledge of an auto construction will help you understand vehicle type. You'll identify the vehicle as a two- or four-wheel or other drive system, does vehicle use frame or not. Knowing information about existing vehicle types helps you to debate with managers in choosing a car or helps you to discuss with a craftsman for a car repair or preventive check.

1.1 Introduction to car systems

A car (automobile) is a road vehicle, typically with four wheels, powered by an internal combustion engine and able to carry a little number of people, a driver and passengers.

In the time, a car division in the parts was changing. Previously was two most important parts of a car, body and frame. Another important element was chassis. Sometimes the chassis was only the frame, but in other times it includes the wheels, transmission and other components. The chassis was one of the most important components of a vehicle, which defines a car structure.

At this point, the composition of the car has changed and a car has become more integrated as a whole. Car body is car fully or partly enclosed part of the car. At present a car body mostly performs the frame function. Also, exist other terms of car, those as cabin, saloon. For instance, a saloon car is a car with seats for four or more people, a fixed roof, and a boot. This is governed by car manufacturers, state laws and various additional rules. The term automobile is derived from the Greek word autos, which means self, and the French word mobile, which suggests moving. It may be possible that the word “car” originates from “carrus” which means two-wheeled Celtic war chariot. Vehicle originate from Latin “vehiculum” which means transport. The term automotive, which was created from Greek “autos” (self), and Latin “motivus” (of motion) to represent any sort of self-powered vehicle. Automotive pertaining to automobiles, for instance, automotive industry, parts or other systems such as electronics. More see in [1.1].

Under construction are battery electric cars or more generally electric vehicles. Cars with electric motors and internal combustion engines is part of hybrid electric vehicles group. Also exist under design fuel cell cars from the group fuel cell vehicles, where fuel (hydrogen+oxygen) directly converts to electrical power (however, it is problematic with application of this sort of energy) [1.2, 1.3].

In general, we will present and discuss cars with internal combustion engines. The knowing automotive principles and systems can be useful for understanding other types of vehicles. We will note that typical car has over 15 000 parts [0.12], which are connected to the whole to make sure smooth traveling. Toyota informs that one car has about 30 000 parts, counting every part right down to the littlest screws. A number of these parts are made at Toyota, but they even have many other suppliers that make many of those parts [1.4]. This is often a beautiful example of achievement within the field of engineering. Automotive parts and systems will be organized in some major categories presented in Table 1.1.

Table 1.1. The major car with internal combustion engine systems (parts).

No.	System (Part)	Components or functionality
1.	Chassis or drivetrain	Frame (optional) Axles, Bridges, Suspension, Driving (Steering), Braking, Wheels
2.	Car body	Can include frame function, Encloses vehicle
3.	Engine	Provide mechanical energy
4.	Fuel, exhaust, cooling, lubrication	Source of energy, engine cooling and reducing friction
5.	Electrical	Wiring, Battery, Starter, Generator
6.	Electronic	Computer, Security, Safety
Note: combination No. 1 and No. 3 parts is named Powertrain.		

1.2 Car drive wheel configurations

A drive wheel may be a wheel of an automobile that transmits force, transforming the torque (rotational or twisting force, see paragraph 6.9) into tractive force from the tires to the road. For this reason, the car may move forward or backward. Those are the following mechanisms to invert the movement. A two-wheel drive (2WD) has two driven wheels. If both drive wheels located at the rear of car that system is named rear wheel drive (RWD). If both drive wheels located at the front that system is named front wheel drive (FWD). While four-wheels drive rear and front, its system is four-wheel drive (4WD). Also, exist other similar system which named All-wheel drive (AWD). Also, in automotive exist other different kind wheel systems. The trailer wheel is one that's neither a drive wheel nor a steer wheel. Front-wheel drive vehicles usually have rear wheels as trailer wheels. Often the car has a spare wheel that usually lies in the trunk and is rarely used. Sometimes on-site spare wheel manufacturers provide a foam balloon for temporary wheel repairs on the road.

Four-wheel drive (4WD or 4x4) by four driven wheels is more traditional system. However, an all-wheel drive (AWD) system may be problematic rigorously to define. We can notify, that the AWD powertrain construction is capable transfer engine power to all wheels or any of it depending on situation all the time. That system also named as full-time four-wheel drive system. AWD and 4WD systems direct power to all or any four wheels - a number of the time or all of the time. Four-wheel drive more refers to systems with a two-speed transfer case, designed primarily for low-speed off-road driving. Often, only the rear wheels are driven in normal operation, with four-wheel drive selected just for extreme conditions. All-wheel drive systems are designed for full-time, all-speed and all-weather driving. At present 4WD and AWD systems work is controlled by car computer. There are the systems that allow you to modify that systems to a two-wheel drive system to save lots of fuel consumption. The four-wheel drive car was characterized by a raised suspension and chassis frame. Now the frame function is integrated into the body of the car. At present the four-wheel drive and all-wheel drive systems are getting more similar for cars. In Table 1.2 is presented grouped car drive wheel configurations. Also, in table is shown how engine is mounted. That and more information is discussed in review articles [1.5-1.7].

Table 1.2. Car drive wheel configurations.

No.	Abbreviation	Wheel drive position	Engine position and orientation
1.	RWD	Rear wheel drive	Front engine Longitudinally mounted
2.	FWD	Front wheel drive	Front engine Transversely mounted
3.	4WD	4-wheel drive (4×4)	Front engine Longitudinally mounted or Transversely mounted
4.	AWD	All wheel drive, all time	Front engine Longitudinally mounted or Transversely mounted
5.	RMR	Rear wheel drive	Rear mid-engine rear-wheel drive (RMR) system is not widely used for passenger cars, impractical

1.3 Rear-wheel drive (RWD) and front-wheel drive (FWD)

There exist two types of two-wheel-drive system: rear-wheel drive (RWD) and forward-wheel drive (FWD). For RWD engine is mounted longitudinally. The engine crankshaft is oriented along the long axis of the vehicle from front to back. For FWD engine is mounted transversely. The engine crankshaft is oriented perpendicularly to the long axis of the vehicle. Many modern front wheel drive vehicles use this engine mounting configuration. Rear-wheel drive (RWD) and front-wheel drive (FWD) drive architectures are shown in Fig. 1.1 and Fig. 1.2. More rigorous definitions of terms powertrain, drivetrain and driveline you may find in paragraph 1.7. Initially those terms we will use more freely.

Rear-wheel drive offers better initial acceleration than does forward-wheel drive when a fast start is of the essence. That's because weight is transferred to the rear of the car upon accelerating, thus boosting traction. RWD also permits expert or higher-class drivers to use various techniques to slip the rear end around corners, which may be a skill most useful in racing. Additionally, by keeping a part of the drivetrain in back, a rear-wheel-drive car usually has weight distribution closer to the optimal 50 percent front and 50 percent rear than are often achieved with an FWD system. Equal weight distribution improves a vehicle's overall balance and handling.

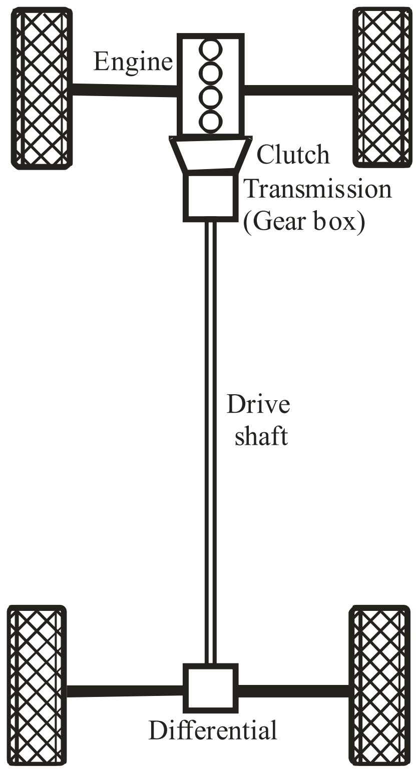

Fig. 1.1. Rear-wheel drive (RWD) driveline architecture. The front of the car is at the top of figure.

RWD advantage doesn't necessarily make rear-wheel drive the best configuration. RWD has its own disadvantages. RWD cars require a driveshaft, and to accommodate it, they need the space-robbing interior hump in the middle of the passenger saloon.

In two-wheel-drive trucks, RWD is important because the rear of the truck is so light that putting the whole drive system up front would make an empty pickup nearly impossible to drive. The rear wheels would almost be floating and would easily lose contact with the surface on even moderately bumpy roads. Conversely, adding load within the rear of an RWD truck or SUV that's hauling cargo or a towing a trailer improves traction. Having the driven wheels close to the point where the trailer is connected to the vehicle via an articulated hitch also helps with steering while towing [1.7, 1.8].

Modern cars don't make much difference whether they are powered either by front or rear wheels. Electronic control systems balance the driving and driving capabilities of both sorts of cars. However, the front wheel drive car has many advantages. It is a spacious and versatile saloon (body). The car is economical, uses less fuel. Rear wheel drive cars need a rear differential to make the 90-degree turn necessary to transfer engine power from the driveshaft to the rear wheels. FWD design doesn't require such 90-degree changing. In this case, all rotating elements from the engine to the drive wheels are on the parallel axles. Essentially, it's smaller in number of rotating parts and lower friction losses. At an equivalent time, the car is cheaper to shop for and cheaper in exploitation.

Fig. 1.2. Front-wheel drive (FWD) driveline architecture. Frequently transmission (gear box and differential) is named as one-unit transaxle [0.7, 0.13, 0.35]. The front of the car is at the top of figure.

However, FWD cars are front-heavy and is not optimal for handling. A problem is that the front wheels have to do two things: transfer the power to the front wheels and steer the car. With a high-power engine it can be difficult to keep the car straight when it starts. Modern FWD cars are more stable on the road as they are equipped with electronic traction control system [1.9]. Neglecting some disadvantages, for FWD car the weight of the engine with transaxle is positioned on the top of the drive wheels, which also helps the car get a well grip. FWD cars are very capable in poor weather and excellently behaves, when fitted with winter tires.

1.4 A four-wheel drive car (4WD)

A four-wheel drive vehicle, which schematically shown in Fig. 1.3, is a four-wheeled car with a drivetrain that allows all four wheels to receive torque from the engine simultaneously. Also exists and all-wheel drive system. In principle four-wheel drive and all-wheel drive both drivetrain systems pursue the equivalent goal. These two systems realize two different ways of delivering traction to all four wheels when they need it. Both systems belong to the all-wheel drive system. The main difference is in the use of a centre differential or also named a transfer differential.

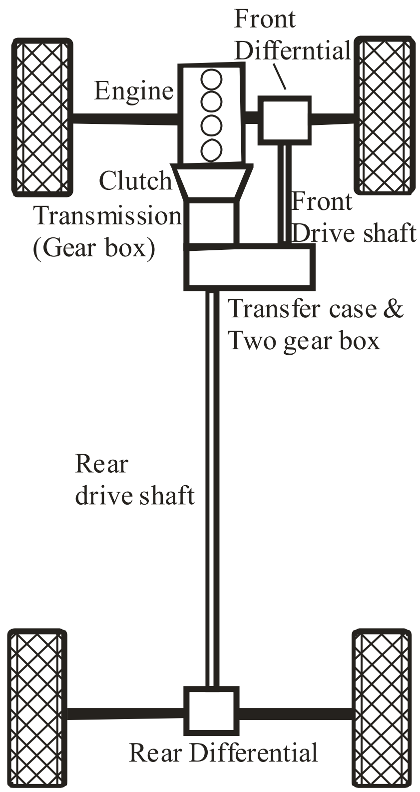

Fig. 1.3. Traditional truck-based 4-Wheel Drive (4WD or 4×4) driveline architecture. The front of the car is at the top of figure.

The definition "Four-wheel drive" comes from a system where there are two axles with a differential on each, connected by driveshafts onto a transfer case. The transfer case is where power from the engine and transmission is sent to the axles to regulate traction. In the old days, this was done manually. A second lever on the floor controlled the transfer case, switching it from two-wheel to four-wheel drive. Firstly, needs the front wheel hubs had to be unlocked by a knob. That knob controlled whether the additional drive axle can be used to increase traction.

Transfer cases normally came with two gears: High and Low. High is where most traction is used – on wet, snowy and dirty roads that are drivable. Low gear is used for more harder situations, like when one must to drive slowly over rolling stones, icy or pity road.

At present, four-wheel drive systems become simple in use. Electronic locking hubs, automated transfer case switching have simplified car control. The driver's attention is now not diverted to additional work while driving. Four-wheel drive systems are commonly found on pickup trucks and traditional SUVs [1.10].

1.5 All-wheel drive car (AWD)

An all-wheel drive (AWD) car transfers power to every wheel simultaneously. AWD can provide maximum forward traction during acceleration. It is especially helpful in sloppy road conditions and when driving over moderate off-road terrain. That can help you get going and keep you moving through mud, sand, and other loose surfaces. Most AWD systems deliver power primarily to at least one set of wheels, front or rear. When slippage is detected at one axle, power is diverted to the opposite axle, in hopes of finding more traction there. Not all AWD systems are equal. Many systems constructed to front-wheel-drive vehicles operate with one hundred percent of the power normally getting to the front wheels. The rear wheels receive power only when the front wheels start slipping.

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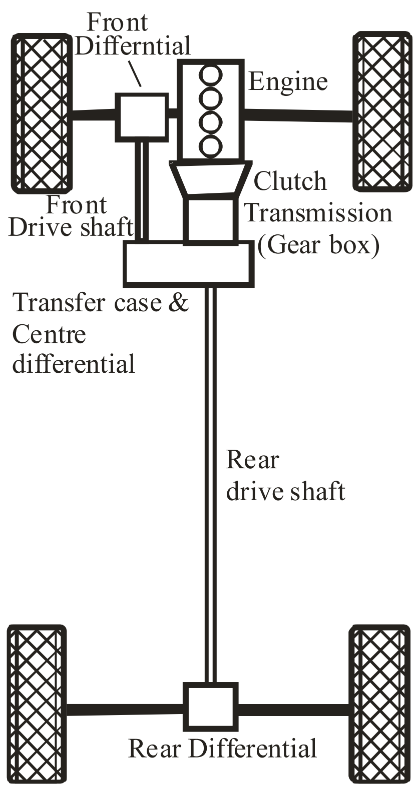

Fig. 1.4. All-wheel drive adapted from rear wheel drive. The front of the car is at the top of figure.

All-wheel drive systems were developed more recently and are far more complicated than traditional four-wheel drive systems [1.11-1.14]. However, it is available in various types of modern cars, from full-size SUV's to sports cars. The most important difference between 4WD and AWD is that an AWD system is active all the time. AWD systems use three differentials. Note, a differential may be a box of gears that transfers power from the transmission and divides it at different points. Speaking more specifically, the differentials either divide torque between two wheels or between the front and rear axles. Because an AWD system uses three differentials, it applies power to the wheels that have the foremost traction by dividing the power between the front and rear axles on the centre differential. Then it is distributed power to the individual wheels via the front and rear differentials.

Modern AWD vehicles transfer engine power to each wheel by redistributing torque to ensure a stable ride. Also exist and other definition of AWD trough Power Transfer Unit (PTU). The PTU is an all-wheel drive transfer case used in cars and sport utility vehicles. It allows to distribute power to all four wheels either part time or full time, and also controls how much power goes to the front and rear by specific driving conditions. AWD vehicles are nearly always based upon RWD or FWD layouts [1.13]. Transforming of RWD or FWD in AWD is shown in Figures 1.4 and 1.5. At this context we will note that the systems are similar one to another but are different from the Subaru AWD system SAWD, which means symmetrical AWD. It is difficult to decide, which system 4WD or AWD is better for you. It depends on the requirements of a vehicle owner. If one lives within the country or up within the mountains and have tough terrain to drive on, a real four-wheel drive system is the right choice. For seasonal weather patterns in town or on the highway, an all-wheel drive vehicle suffices. However, a customer's actual choice varies with their practical need. About that and more see in Refs. [1.11- 1.14].

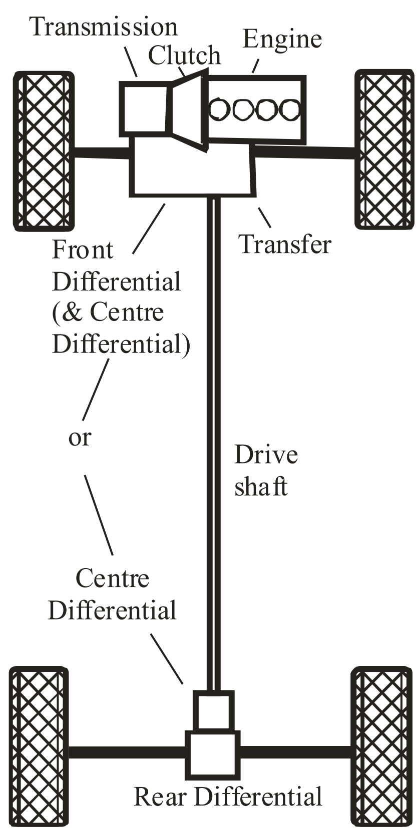

Fig. 1.5. All-wheel drive adapted from Front-wheel drive. The front of the car is at the top of figure.

1.6 Symmetrical All-wheel drive car

Subaru designed symmetrical full-time All-Wheel Drive with longitudinally mounted Horizontally-Opposed BOXER (Flat engine). It is an exclusive AWD system designed to employ all four wheels at all time. The complete system schematically shown in Fig.1.6. Every component helps to make sure stable and balanced performance of the car [1.15]. The boxer engine is the flat engine, where each pair of pistons in opposed cylinders moves inwards and outwards at the same time. This interesting symmetrical AWD, is similar to the RWD design, because it has a longitudinally balanced distribution of weight. Symmetrical layouts laterally, leading to equal axle lengths and even weight distribution balance transversally.

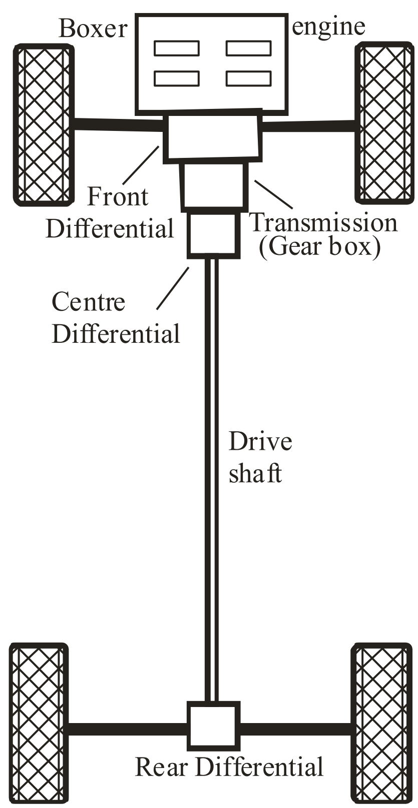

Fig. 1.6. Subaru symmetrical All-wheel drive (AWD) driveline architecture. The front of the car is at the top of figure.

Subaru uses more than one sort of centre differential. There may be used viscous coupling locking type and, more advanced its DCCD (Driver-Controllable Centre Differential) system. DCCD is formed from two differentials. It consists of a planetary gear-type unit and an electronically controlled limited-slip type. The system allows to control centre differential from inside the saloon. For example, the centre differential may be tightened for increased traction on slippery pavement.

All Wheel Drive does make you safer? Yes, but not necessarily in all cases. We will quote a more consistent explanation there [1.11]. Many of us buy a standard sport-utility vehicle for the additional safety and traction of four-wheel drive. Part of drivers do not realize the limitations of AWD and 4WD, however. Though having power delivered to all or any four wheels increases straight-line traction, it does not enhance cornering or braking. Drivers are often overestimating their abilities when driving in slippery conditions with an AWD or 4WD vehicle. They do not understand dangerous of slippery conditions. They are going way too fast thinking that AWD or 4WD helps to prevent slippering. Because the added traction of AWD and 4WD can allow a vehicle to accelerate more quickly in slippery conditions. Drivers got to be more vigilant, not less. Slippery conditions demand extra caution, regardless of what you are driving. In many cases, having good tires is more important than having the all drive wheels. Winter tires, as an example, actually do help you turn and stop on a snowy road. Active safety systems make FWD, RWD and 4WD cars similarly safe as AWD (see, for instance, Chapters 3 and 5).

1.7 All-wheel drive systems

All-wheel drive systems are more complicated and we initially define only a few terms. The vehicle power aggregates could also be divided in a few systems.

The primary system and main is powertrain. It includes the engine and other parts that makes the vehicle to move.

The second system may be a drivetrain. It's a part of a vehicle which connects engine to the wheel axles.

The third system is driveline. The driveline includes everything from the transmission (gearbox) to the drive wheels. It includes driveshafts (depending on driving system), axles, differentials, wheels. In literature most used are powertrain and drivetrain terms.

The term chassis is also used. It is the skeletal framework of a vehicle on which now of the mechanical parts like wheels, axle assemblies, steering, brakes, and the engine are fastened. It is reminiscent of a previously used frame on which car parts were attached.

In the simplest case, the all-wheel drivetrain system consists of viscous fluid-filled differentials and advanced electronics enabling the engine to send power to all four wheels. This provides a vast and highly improved capability for driving on wet or slippery roads. A **permanent full-time all-wheel drive** vehicle has a permanent torque split between the front and rear axles. Also, it cannot be disabled by the driver or by an electronic control module. At present there exist various AWD drivetrain systems. We will deliver some of them in Table 1.3. We will provide a brief overview of these systems in the next two paragraphs.

Table 1.3. AWD drivetrain systems.

System	Engine	Centre (transaxle) Differential/Control Distribution	Front Differential/ Control	Rear Differential/ Control
Audi quattro	Front	Torsen, two outputs Front & Rear (F&R) Mechanical self-locking 40:60 (F:R) Crown Gear		
BMW xDrive	Front Longitudinal mounted Front (new) Transversely mounted	Multidisc (multiplate) wet clutch 40:60 (F:R) High Speed Servo motor, 0.1 s Up to 100% FWD		Dynamic Performance Control (DPC)
Ford Intelligent (new Disconnect) AWD	Front	Automatically adjusts the torque distribution between the front and rear wheels		
Honda SH-AWD	Front	Multiplate clutches in rear differential, Electromagnetic		Hypoid gear Left/Right multiplate clutches
Hyundai HTRAC	Front	Dual clutch system		
Kia Dynamax	Front	Multidisc clutch		
Mazda i-ACTIV AWD	Front	Clutches Electromagnetic		
Mercedes 4MATIC (4-wheel drive and automatic)	Front Longitudinal mounted Front Transversely mounted (new gen.)	Planetary, Multiplate clutches Open Integrated in rear differential	Open Open	Limited slip Open Multi-disc clutch, hydraulically-actuated
Mitsubishi Motors Super All Wheel Control S-AWC	Front, Transversely mounted	Active Centre Differential (ACD) electronically controlled (electromagnet)	Active front differential (AFD),	Active Yaw Control (AYC), (rotation car around vertical Y axis)

		hydraulic multi-plate clutch		
Nissan ATTESA	Front	Viscous coupling		
Range Rover	Front	Transfer box Torsen Bevel-Gear Multi-plate clutch		
Subaru Symmetrical All Wheel Drive (SAWD)	Front Longitudinal mounted Flat Boxer	Viscous LSD (Limited Slip Differential) Multi-plate clutch		
Toyota AWD Dynamic Torque Control (DTC) (Old name All-Trac)		Multiplate clutch		
Volkswagen 4motion (Old name Syncro)	Front, Transversely mounted Longitudinal mounted	Haldex Torsen		

1.8 Differentials for AWD

In this paragraph you may find brief overview differentials for AWD systems [1.16-1.18].

Full-Time All-Wheel drivetrain uses three differentials to spread the power (torque) effectively between all four wheels. The wheels are all receiving power all of the time over this layout. Here we'll present the ways through which this is often achieved. This field is additionally rapidly developing, especially for management using automatic computer technologies. Over this way, the systems acquire ever new names, which somewhat reveal the essence of operation.

Right now, the most important goal is to control distribution the power between the wheels with the electrical signals. This needs not only appropriate actuators but also torque sensors. That sensors are going to be discussed extensively enough at the end of the book.

1.8.1 Torsen differential

The Torsen differential comes from Torque Sensing and it's a limited-slip mechanical differential. This type of differentials was manufactured by the Gleason Corporation [1.18]. They can be used as front/rear differential or as central (inter-axial) differential. Torsen differentials are fully mechanical, with satellites and helicoid gears. Their self-locking characteristic depends on torque difference sensing between front and rear axles or between left and right wheels. The Torsen named T3 centre (C) differential combines a planetary gear set with a Torsen differential in a compact package developed for centre differential installations.

1.8.2 Crown gear differential

Audi developed a new kind of centre differential called crown gear differential. Like the Torsen C differential, the crown gear differential is default set to 40:60 torque split between front and rear axles under normal condition, so it is able to deliver a handling characteristic more similar to rear-drive cars. When the front axle loses traction, it may send up to 85% torque to the rear. When the rear slips, it transfers up to 70% torque to the front. Such locking range is much wider than the case of Torsen C differential. Neglecting that included rear and front multiplate clutches for redistribution rotation moments, the crown gear differential is simpler in construction and weighs less than Torsen C [1.16, 1.19].

1.8.3 Multidisc (multiplate) clutch

Multi-plate clutches work with several friction discs, unlike dry friction clutches used in most cars with manual transmissions where only one friction disc with two friction surfaces is used to transmit power from the engine to the transmission.

A multiple plate clutch is a type of clutch system where multiple driven and drive plates are used in order to make up for torque loss due to slippage. This slippage is usually caused by a fluid that the plates are immersed in it for cooling, cleaning and lubrication. The idea for an electronically controlled four-wheel drive system emerged at BorgWarner (American worldwide automotive industry components and parts supplier) in 1985. BorgWarner's original design called for using both a software controlled electromagnetic multi-disc (also called multi-plate) clutch pack and a planetary or bevel geared centre differential together [1.20, 1.21].

1.8.4 Planetary gear central differential

A planetary gear train is an assemblage of three components: a ring gear, a planetary carrier with one or more pinion gears (planets), and a central sun gear (see Fig. 3.4).

The CD/VCU (Central differential/Viscous coupling unit) is the basis of the AWD system [1.22, 1.23]. Exists cases when a planetary gear is used in a 4WD as centre differential. In this case the ring gear, pinion gears, and sun gear in that CD/VCU system are spur gears, which have straight teeth that are parallel to the shaft. The carrier is that the driving component and both the ring and sun turn at different speeds to split torque unevenly (33/67) between ring and sun gear.

1.8.5 Viscous limited slip differential (VLSD)

Viscous limited slip differential uses a viscous coupling that allows for torque to transfer to the wheel with more grip. It is an alternative method to a clutch pack differential. It is not very effectively locking the two driveshafts. On the other hand, it is a simple construction. The viscous coupling is often adapted in AWD vehicles. It is commonly used for centre differential. The viscous coupling has two sets of plates inside a sealed housing that is filled with a thick special fluid. One set of plates is connected to each output shaft. Under normal conditions, both sets of plates and the viscous fluid rotates at the same speed.

When one set of wheels tries to spin faster, perhaps because it is slipping, the set of plates corresponding to those wheels spins faster than the other. It follows from physics that the coefficient of friction of a viscous fluid strongly depends on the speed of movement. The higher the speed, the greater the resistance or friction. The viscous fluid, stuck between the plates, tries to catch up with the faster disks, dragging the slower disks along. This transfers more torque to the slower moving wheels [1.24].

Torque is transmitted by the viscous coupling, which utilizes the viscosity of silicone fluid. The stability of the fluid is the key point for the durability and reliability of the coupling. High-viscosity dimethylsilicone oils are usually adapted as the basic fluids for the viscous coupling [1.25].

1.8.6 Haldex Limited slip differential

Haldex AWD systems are based on a central coupling device with a wet multi-disc clutch. They are manufactured by Haldex Traction AB group, currently owned by BorgWarner. Haldex systems are usually used as rear axle limited-slip differential. The Haldex limited-slip differential is controlled by an electronic control module (ECM). Through the multi-disc clutch position (open, closed, slipping), the vehicle will be operated as an FWD vehicle or AWD vehicle. The torque split between the front and rear axles is variable, depending on the clutch position. The Haldex system is controlled through an electro-hydraulic actuation (EHA) system [1.18], which eliminates the need of hydraulic pump and tubing.

1.9 Short overview of All Wheel Drive systems

All-wheel drive is a much more recent innovation and is on a fast development. With the new car model, you can expect a completely new all-wheel drive system, potentially more advanced system. It is worth to know the achievements in this area. So, let's take a brief look at some of the known AWD systems, which was presented previously in Table 1.3. Also, for more reading see in Refs. [1.16, 1.18, 1.26-1.29].

1.9.1 Audi Quattro AWD

Audi quattro is a permanent four-wheel drive system. If the wheels of one axle lose grip and threaten to spin, the drive torque is redirected to the other axle – automatically and continuously distributed through the self-locking centre differential with torque vectoring (vary the torque to each wheel). The basic distribution is 40:60 – with 40% of the power going to the front axle and 60% to the rear. If necessary, however, up to 70% of power can be directed to the front and up to 85% to the rear to counteract wheel slip [1.30].

The newest sixth-generation Quattro system is currently only available on the RS5, which can alter torque application by sending up to 70 percent of available power to the front axle or up to 85 percent to the rear. This new Crown Gear differential is more rugged than the Torsen type of the fifth generation and is meant to eventually replace the older system. This system was later adopted by the A7, latest generation of the A6 and A8 [1.31].

1.9.2 BMW xDrive AWD

BMW xDrive is BMW's permanent all-wheel drive system. The main component of the xDrive system is the transfer case.

The transfer case is a box filled with mechanisms controlled electronically. The purpose of the transfer case is to split the power coming from the gearbox between front and rear axles, see Figs. 1.3-1.5. The torque control between front and rear axle is performed through a wet multi-disc clutch inside the transfer case. The clutch position is actuated with an electric motor by an electronic control module. When the clutch is fully closed, the torque split is 50:50 between front and rear axle. In normal driving conditions, it works with a basic torque split of 40 to 60 percent between front and rear axle. The torque bias between the axles is adjusted according to different road friction coefficient or driving situation [1.32].

The older systems used a transfer box with a wide chain transferring the power to the front. In the new system a gear train is used and power distributed by a multi-plate wet clutch between axles. The clutch is controlled by a cam which in turn is operated by a high-speed servo motor. That system reaction time is said to be under 1/10 th of a second. Dynamic Performance Control (DPC) is a modified rear differential which is an additional system to basic xDrive and became available in 2008. DPC controls the power distribution to each rear wheel. It has electrically operated clutch packs on each differential output These select one of two planetary gear sets giving the ability to overdrive one of the transaxles and thus turn one wheel slightly faster than the other [1.33].

The other variation of the xDrive system is installed in the 2015 BMW X1 (F48), which is based on a front-wheel drive design with a transversely-mounted engine [1.34]. In the FWD-derived xDrive variant, the front wheels receive 100% of the torque when the xDrive clutch is open and car becomes FWD.

1.9.3 Ford Intelligent (new Disconnect) AWD

Currently, Ford AWD’s work has become highly dependent on electronic systems: sensors, actuators, and computer programs. Ford is calling the new tech All-Wheel Drive Disconnect. It is different from the intelligent AWD found on current Edges. The old system determines axle torque split interpreting various traction and driving variables. The new system has a more advanced construction. The new Edges are capable of running in full front-wheel drive. The rear axle may be completely disconnected. It is doing automatically by a computer [1.35].

At the moment Ford Explorer experienced changes. It is that the 2019 model has standard FWD, and the 2020 Explorer returns to its roots of rear-wheel drive. Ford created an SUV whose engineering has more in common with vehicles from BMW and Mercedes than traditional competitors from Chevrolet, Honda and Toyota. Ford Explorer 2020 change engine direction [1.36]. The new 2020 Explorer has a rear-wheel-drive-based architecture and optional all-wheel drive. That’s a major change from the outgoing model 2010-2019, which had base models that were front-wheel-drive and optional AWD.

That means the 2020 model’s engine lines up in the same direction as the vehicle (longitudinal), while the 2010-19 Explorer engines sat crosswise, on the line between the front wheels (transverse). In this case, higher power engines may be used.

1.9.4 Honda SH-AWD

Super Handling-All Wheel Drive or SH-AWD is a full-time, fully automatic all-wheel drive traction and handling system designed and engineered by Honda Motor Company. We note, Acura is the luxury vehicle marque of Japanese automaker Honda. The brand was launched in the United States and Canada in March 1986, marketing luxury, performance, and high-performance vehicles. Honda in 1995 introduced as the name for its car-based utility vehicle, the acronym CRV which represents a mix between a car or minivan and a sport utility vehicle, or SUV. Some say, it stands for "compact recreation vehicle," while others insist it's short for "comfortable runabout vehicle”. The Acura SH-AWD system (short for: **S**uper **H**andling-**A**ll **W**heel **D**rive) is often described ambiguously in most automobile literature [1.37].

The SH-AWD is similar to an AWD system which uses a planetary gear central differential with multi-plate clutch acting as limited slip feature. The difference is, SH-AWD uses two of such differentials, one for each wheel. The system combines front/rear torque distribution control with independently regulated torque distribution to the left and right rear wheels to freely distribute the optimum amount of torque to all four wheels in accordance with driving conditions. Electromagnetic clutches continuously regulate and vary the front/rear torque distribution between ratios of 30:70 and 70:30 [1.38].

1.9.5 Hyundai HTRAC AWD

HTRAC is an exclusive technology by Hyundai Motor that is based on AWD technology. That name comes from a combination of the H from Hyundai and the beginning of the word Traction to represent the technological characteristics of 4WD. The innovative AWD is equipped with Hyundai’s new HTRAC All-Wheel Drive (AWD) system. HTRAC is a multi-mode system, providing an electronic, variable-torque-split clutch with active torque control between the front and rear axles. To get optimal weight balance and driving dynamics, Hyundai engineers produced one of the lightest all-wheel drive systems in use today, at just 75 kg.

An Intelligent Driving Mode allows drivers to select from three operational modes designed to maximize driving safety in all conditions and for all driving preferences. Each mode sets appropriate power distribution, throttle responsiveness, stability control and suspension damping settings. Selected modes are applied seamlessly by the HTRAC system [1.39, 1.40].

1.9.6 Kia Dynamax AWD

The DynaMax AWD system is basically similar to others which are using an electric motor and oil pump to actuate a multidisc clutch. The hydraulic pressure applies to the clutch, so required torque is transferred from the front-drive-based system to the rear differential - the greater the pressure, the more torque is shifted to the rear.

However, there are different advantages vs. other traditional systems. The DynaMax AWD system uses torque vectoring control technology. That allows car to control how much power get certain wheels. Also, AWD advances is related within the coupling system and with the high level of active control system. The control is at higher speeds and that allows to enhance overall performance of the system [1.41].

1.9.7 Mazda i-ACTIV AWD

The Mazda i-ACTIV AWD employs a system of sensors that monitor acceleration, brake pressure, steering torque, vehicle speed and engine power to optimize car work. Mazda i-ACTIV ALL-Wheel Drive System delivers approximately 98% of engine power to the front wheels in normal operation on dry and even surfaces. However, when necessary, torque transfer can reach as much as 50:50 front-to-rear in slippery conditions. Where many AWD systems are touted as sending power from the wheels that slip to the wheels that grip - a reactionary system - Mazda's i-ACTIV AWD is predictive. It evaluates the road and weather conditions and monitors data from the engine, transmission, yaw sensors, steering system and even the use of the windscreen wipers. All the data is sampled at more than 200 times per second and analysed to determine torque transfer. In all, i-ACTIV AWD uses 27 different sensors that feed to a central control module to determine how wheels need to be driven before the ever reach a patch of ice or deep puddle [1.42, 1.43].

The processing power is incredible. Every second, Mazda's i-ACTIV all-wheel-drive (AWD) system monitors a network of inputs and sensors, two hundred times. That's a full check of individual wheel speeds, brake and throttle pressure, steering angle, inclination, outside temperature, and even whether the wipers are activated. That's the job of the lowly power coupler, a small cylinder full of clutches and electromagnets, stacked one over the next, about the size of a coffee can. The coupler mechanically joins the front drive axle to the rear, to varying degrees, depending on the state of the clutches inside. Just 3 amps applied to the coupler's electromagnets locks the clutches, and both drive axles, together. Less amperage means less bite from the clutches, and less power to the rear wheels. With no current applied, the coupler is open, and the vehicle is front-wheel drive [1.44, 1.45].

1.9.8 Mercedes 4MATIC AWD

4MATIC is the AWD/4WD technology developed by Mercedes-Benz. 4MATIC is fully integrated system into the drivetrain. The central planetary differential splits the torque between the front and rear axles. The first generation of 4MATIC was using an electronically controlled central differential, a rear limited-slip differential and a front open differential. The latest generation of 4MATIC system is using three open differentials (front, rear and central) [1.18].

The mechanical structure of the 4MATIC is based on the standard rear-wheel drive. A transfer case is installed to the automatic or manual transmission. This transfer case transmits power from the transmission output shaft to the front and rear axles at a ratio of 35/65 %.

The transfer case contains the central differential within the sort of a planetary gearset. To control torque distribution two hydraulically actuated multidisc clutches are used. The multidisc clutches are activated by solenoid valves which are incorporated in one valve block [1.46].

New generation the 4MATIC all-wheel drive is a completely new development and was designed specifically to work with the new front-wheel drive models. In the new 4MATIC system is used hydraulically actuated multi-disc clutch. This set-up allows a fully-variable torque to distribute between the front and rear axles [1.47, 1.48].

1.9.9 Mitsubishi Super All Wheel Control S-AWC

The S-AWC (Super All Wheel Control) is the name of an advanced full-time four-wheel system developed by Mitsubishi Motors. The technology, was specifically developed for the new 2007 Lancer evolution, the 2010 Outlander (if equipped) and for the 2014 Outlander. S-AWC is an Integrated Vehicle Dynamics control system that realizes the AWC concept at a really high level. Its advanced integrated control manages the driving forces and braking forces of the four wheels to assist the realization of vehicle behaviour that's faithful to the driver operating under a spread of driving conditions. S-AWC utilized in Outlander adds Active Yaw (rotation around the vertical axis) Control (AYC).

That controls the brakes and power-assisted steering to manage the torque split between the left and right wheels,

Also, the system may include active Front Differential (AFD), which is front electronic controlled LSD (Limited Slip Differential). It limits the differential speed between the right and left front wheel by an electronic control clutch, and controls the driving torque distribution of front axle to the 4WD drivetrain.

This leads to further enhancements within the car's ability to accurately trace the chosen line through corners, in stability of both straight-line driving and lane changing manoeuvres and in traction control on slippery surfaces.

The S-AWC drivetrain on the new Outlander offers four modes of operation. AWC ECO feeds torque just to the front wheels under normal conditions for fuel economy while switching to 4WD when slippery surfaces are encountered. NORMAL optimally regulates torque feed to every individual wheel in accordance with driving conditions. SNOW mode provides optimal traction and handling control when driving over ice, snow or other slippery surfaces. LOCK mode delivers the complete capabilities of 4WD all-terrain performance. The driving force can be selected using any of those modes manually [1.49].

The S-AWC fabricated on the Mitsubishi Motors include (All-Wheel Control) AWC technology with the addition of torque vectoring capabilities. The S-AWC also integrates other several technologies. The Active Front Differential (AFD) distributes engine power between left and right of the front axle. Active Stability Control (ASC) helps to keep the vehicle on its intended path when cornering, and therefore the Anti-lock Braking System (ABS), alongside Electronic Brakeforce Distribution (EBD), improves control and stability under hard braking.

With the push of a button, the driver can select one from four S-AWC modes to assist in achieving maximum available traction depending on matter surface conditions. Those modes include Normal Mode, Snow Mode, Lock Mode and AWC ECO Mode [1.50, 1.51].

1.9.10 Nissan ATTESA AWD

ATTESA (Advanced Total Traction Engineering System for All-Terrain) is a Nissan AWD system. The ATTESA system was developed for transverse mounted engine vehicles. The Electronic Torque Split (ATTESA E-TS) version is a more advanced system developed for Nissan vehicles with a longitudinal drive train layout. Other ATTESA E-TS Pro differs from the standard ATTESA E-TS in a few ways.

The ATTESA E-TS controls the front to rear torque-split, however the Pro system is also capable of left-and-right torque split of the rear wheels.

The Nissan design used an electronic-controlled multi-plate clutch to connect the front axle. Its clutch plates were actuated by a single hydraulic circuit [1.26. 1.52]. The primary function of the ATTESA controller is to electronically regulate the amount of torque split across the centre differential. The amount of torque sent to the front wheels could be as little as two percent or as much as 50 percent.

The ability to electronically control the LSD in the rear differential also may be included.

AWD vehicles are equipped with a centre differential, which is composed of gears that split power from the transmission to both front and rear axles.

Wheel sensors function is to detect traction losses, indicating which wheels require add power. Nissan’s Intelligent AWD system detects these changes and automatically responds by sending power to the appropriate wheels. Nissan’s Intelligent AWD is also possible to maximize efficiency by sending power to the front wheels at higher speeds, and adapting to transfer power between the front and rear wheels when road conditions change.

It realizes more economical driving on the highway. This feature makes it a great choice if you live in an area with heavy rain or snow, or you plan to take your vehicle for light off-roading. Therefore, the Nissan AWD is not just for rugged off-road vehicles either. The Nissan ATTESA helps to distribute torque to the front and rear wheels, depending on the tire slip or changes in road conditions.

1.9.11 Range Rover AWD

The Land Rover and the Range Rover are both cars manufactured by the Tata Group's Jaguar Land Rover group. Land Rovers are SUVs, whereas Range Rovers are oriented more towards the premium segment [1.53].

The models presented in this description deals with Range Rover from 2013, and Range Rover Sport from 2014. We present a brief technical description on Range Rover's AWD systems. Two different types of AWD systems are used on these SUVs. If the Range Rover or Range Rover Sport is equipped with the single speed transfer case, then its AWD system is using a Torsen-C centre differential. Range Rover Sport is manufactured with Torsen-C centre differential and has not a differential lock. It also cannot get the rear differential lock feature too. If the Range Rover or Range Rover Sport is using a two-speed transfer case, then its AWD system include bevel-gear plus multi-plate clutch limited-slip differential 1.54, 1.55].

1.9.12 Subaru Symmetrical AWD (SAWD)

Automobile manufacturer Subaru developed symmetrical All Wheel Drive (SAWD). This unique SAWD system is a full-time four-wheel drive system. This means that its All-Wheel Drive systems are full-time and constantly on, delivering drive/torque to both the front and rear axles as required.

The SAWD system consists of a longitudinally mounted boxer (flat) engine coupled to a symmetrical drivetrain with equal length half-axles.

Subaru also manufacture a number of different All-Wheel Drive systems for the different model. Subaru use four different all-wheel-drive systems on different types of its cars. Below are listed that four different systems.

1. Base. Centre Differential is Viscous Limited Slip Differential (LSD). This system is used for models equipped with manual transmissions.

2. Base. Uses Active Torque Split + Multi-Plate Transfer Clutch System AWD. This system creates more predictable handling.

3. Advanced. Variable Torque Distribution (VTD) AWD. Connected to CVT (continuously variable transmission). Also, this AWD system delivers sportier performance. The centre differential adjusts front/rear torque split. The viscous self-locking rear differential supports stability when more torque is sent to the rear wheels.

4. Advanced. Driver Controlled Centre Differential (DCCD) AWD. The DCCD allows the driver to adjust the centre differential. Exists one manual and three automatic modes. The AWD system also includes a helical-type front differential and a TORSEN rear differential, creating a triple-differential set-up that is completely unique in the automotive industry [1.15, 1.56-1.58].

1.9.13 Toyota AWD with Dynamic Torque Control (DTC)

Earlier Toyota's full-time symmetric four-wheel drive system was named All-Trac. It was used on a range of its models from 1988 to 2000. Toyota were constructed electronic/vacuum-controlled locking centre differential. It had been a revolutionary advance for four-wheel drive cars. The centre differential was installed in the rear of the car. At the present Toyota all-wheel drive (AWD) provides power from the engine to all four wheels.

Dynamic Torque system helps to control the proper amount of torque where it is needed now. Toyota AWD send power to the front wheels as well as to the back wheels via a rear differential which also include centre differential function.

Toyota models, may send up to 100% of power to the front wheels (disconnect rear wheels) at any time and up to 50% of power to the rear wheels (partly connect rear wheels) when it needed. The electronic control system also uses information collected from sensor: vehicle speed, steering manoeuvres, throttle position, Yaw rotation rate and other. Front wheel drive is employed in normal conditions. Torque transfers to rear wheels via electronically-controlled multiplate clutch. The clutch is often manually locked using a button on the console [1.59-1.61].

1.9.14 Volkswagen 4motion AWD

The Volkswagen 4motion all-wheel drive use two different systems. They include electronically controlled-multiplate clutch and Haldex or Torsen differentials. The control unit monitors wheel slip, handling conditions and drive torque and properly distributes power to the wheels [1.62].

The Haldex differential is installed in front of the rear axle differential and is component of the rear differential case. Yet, it functions as a centre differential. Its hydraulic and electronic systems automatically detect wheel slippage and distribute the tractive force to the two axles accordingly. Haldex system serves to respond optimally to any driving situation.

The Haldex centre differential is driven by the prop shaft. Engine torque is transmitted through the gearbox to the prop shaft. The prop shaft is connected to the input shaft of the Haldex differential. In the Haldex differential the input is separated from the output. Torque can only be sent to the rear axle differential when the Haldex differential clutch plates are on. In the absence of wheel slippage, the clutch plates are not engaged. Only front-wheel drive operates until power is needed for the rear axle [1.63]. That system results in fuel usage efficiency compared to permanent four-wheel drive. In other system used is the Torsen differential, which regulates power between the front and rear axles, using torque sensing [1.64].

1.10 Car classification

Buying a car is an important decision in your life and the first acquaintance starts with the exterior of the car. From this we will begin our presentation. Everyone has their own set of requirements and needs: colour, size, price, fuel efficiency, safety, comfort, luxury and style. Car classification is subjective. Many vehicles depend on multiple categories. In several countries the classification could also be different. Vehicles are often categorized in various ways. For instance, they are often divided by the body style, number of doors, number of seats. One among the primary and most vital things to be included into consideration should be the car body style, which is said to be practical in using the car.

1.10.1 Car dimensions

Now cars are divided into a pair of box, 2-box or 3-box (engine, passenger, cargo) body styles. The body construction includes pillars. Pillars are the vertical or near vertical supports of a car's window area and makes body construction more stable. A sedan or hatchback have 3 pillars, while an SUV or station wagon have 4 pillars. Body styles are partly associated with car dimensions. We firstly define what is an average car. The car size is often expressed in three dimensions: Length L, Width W and Height H (See Fig. 1.7). The car length varies more for various models than other two parameters. The width is more standardized, since all vehicles need to drive within the same highway or street lane.

The vehicles must be adapted to the prevailing infrastructure such as roads, parking spaces, garages, which changes more slowly than vehicles. The standard car size is often defined as length L = 4.50 m and width W = 1.80 m [1.65]. A car's width is defined as its widest point without its mirrors. You'll be able to fold the mirrors on both sides. Cars height approximately is between 1.5 m and 1.8 m [1.66], that average value is about H = 1.65 m. In the Fig. 1.7 also shown other three parameters: Wheel Base WB, Axle Track AT and Ground Clearance GC.

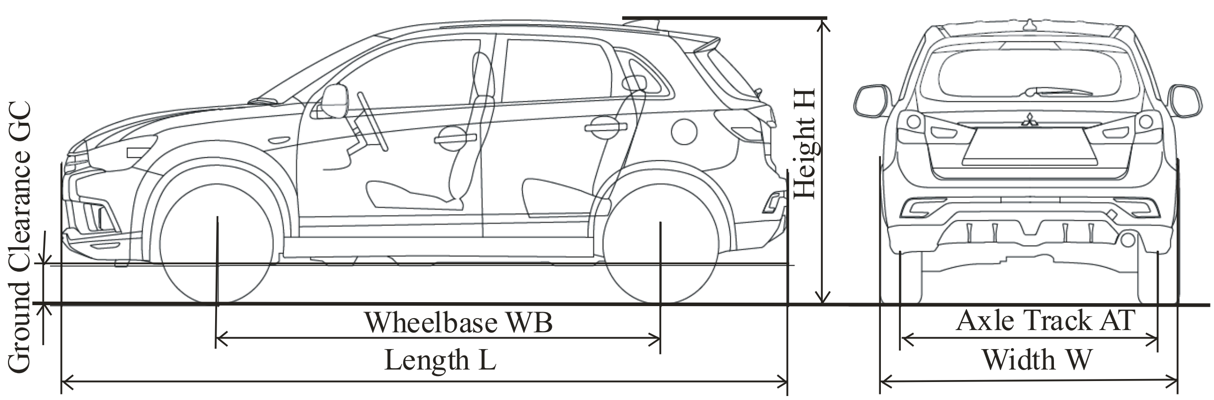

Fig. 1.7. Car dimensions. The car size may be expressed in three dimensions: Length L, Width W and Height H. Also, shown other three parameters: Wheelbase WB, Axle Track AT and Ground Clearance GC.

The wheelbase is the distance between the centres of the front and rear wheels. Although the term wheelbase does not directly reflect the length of the vehicle. However, the longer the wheelbase, the longer is that the overall length of the vehicle. Wheelbase dimensions are important to the balance and steering. In high-speed vehicles an extended wheelbase makes the car more stable at higher speeds. Wheelbase influences a vehicle's turning radius. It's known that the smaller the wheelbase the better it's to manoeuvre the vehicle. The average wheel base for cars is about WB = 2.67 m.

Axle track (track width) is the distance between centrelines of tire tread measured across axle. Note: front and rear axle tracks could also be slightly different and it may also depend on tires (wheels) width. Width of tires are typically equal to 200 mm. From the car width of 1.8 m the calculated axle track is AT = 1.6 m. From wheelbase and axle track we define wheelbase to axle track ratio which is $WB/AT \approx 1.7$. This ratio is analogous for several cars.

Ground clearance is the distance from the lowest-hanging point under a vehicle towards the ground. Adequate clearance allows a vehicle to drive more easily off-road or in snow. One drawback is that the higher ground clearance determines a higher centre gravity of the car. Vehicles with a lower ground clearance centre of gravity are going to be better handling. At the present that problems solve with helps of automatic stability and electric power steering systems. The bottom clearance for normal cars is about GC = 150 mm. On rough roads, higher ground clearance is usually better.

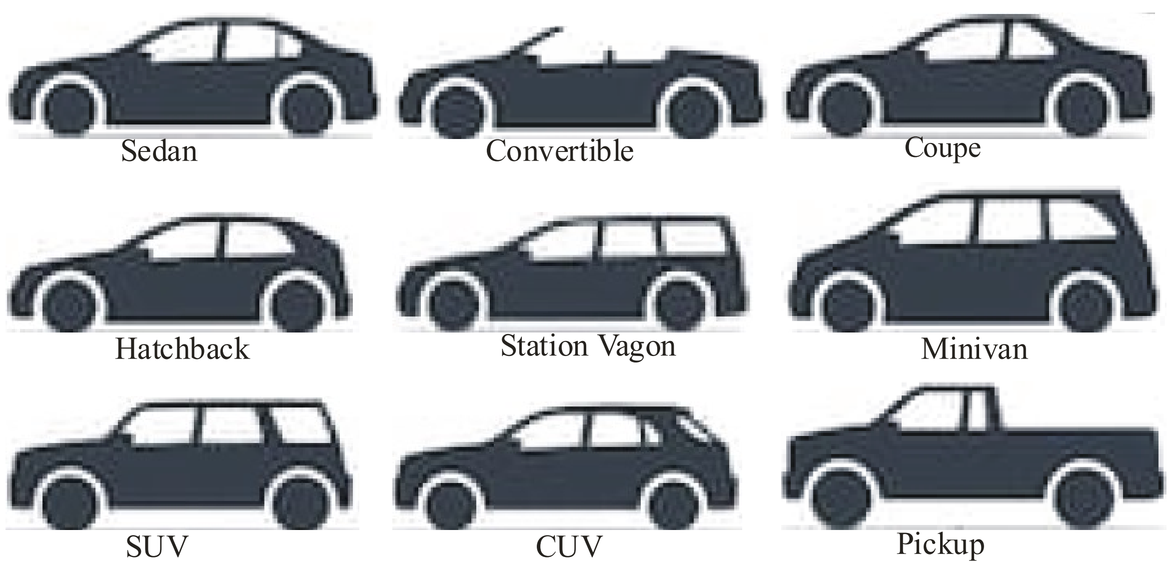

Fig. 1.8. Car body styles at glance. Adapted from [1.67]. SUV means sport utility vehicle, CUV means crossover utility vehicle.

A car's netto mass (without passengers) may vary in the range of 800 up to 2000 kg, average 1300-1500 kg. For most cars, the capacity of the fuel tank is in the range of 45-65 litters. In average with full tank, you can drive about 800-1000 km (more real 800 km). Fuel reserve is about for 50 km. Better tank fill earlier than low fuel level warning light on.

The different car body styles at glance are shown in Fig. 1.8. The descriptions and dimensions of various body styles and other useful information are often found in Refs. [1.68-1.71]. It is now visually difficult to distinguish or recognize cars. Their forms are transformed permanently and they become similar one to another. Now, an equivalent car is often both with a front (rear) wheel or a four-wheel drive system. Short descriptions of some selected cars are presented below. Information about car dimensions is presented at the bottom of the pictures 1.9-1.17. The knowledge contained herein is freely available to consumers. Information of this paragraph was collected from manufacturers official offices as printed material (brochures, presentations, technical data) and from manufacturers online material (presentations, catalogues, brochures or manuals).

1.10.2 Sedan

A sedan (for example, see figure 1.9) or saloon is a passenger car in a three-box configuration with 3 principal separate volumes for engine, passenger and cargo. It has front and back seats and will carry frequently 5 people. Both two-door or four-door are available, but generally referred as a 4-door car. Sedans can vary in size, length and volume. As a result, this body is attractive to conservative buyers. However, sedans are not very practical. This type of vehicle is referred to as a saloon in the UK. Its advantage is that the rear window is always clean and does not require an additional rear window wiper.

Fig. 1.9. Sedan. BMW 5 series sedan (2017). Length L =4.936 m, width W = 1.868 m, height H = 1.479 m, wheelbase WB =2.975 m, front/rear axle track AT = 1.605/1.630 m and ground clearance GC = 144 mm.

1.10.3 Convertible or Cabriolet

A convertible (for example, see figure 1.10) or cabriolet is a passenger car that can be driven with or without a roof in place. The methods of extracting and storing the roof vary between models. Most convertibles are two-door models. It is sporty, less practical for everyday use. Similar car is roadster. A roadster is a convertible but a convertible is not necessarily a roadster. Roadster defines a vehicle that has an open top, two doors, two seats, and is made for sport.

Fig. 1.10. BMW 4 series convertible (2016). Length L = 4.638 m, width W = 1.825 m, height H = 1.384 m, wheelbase WB = 2.810 m, front/rear axle track AT = 1.545/1.594 m and ground clearance GC = 130 mm.

1.10.4 Coupe

A Coupe (for example, see figure 1.11) is a car with a fixed-roof body-style usually with two-doors, often sporty in nature. The precise definition of the term varies between manufacturers and over time. A coupe generally has either 2 seats, or 4 seats placed in a 2+2 configuration, meaning that there are only 2 seats in the rear (as opposed to the standard 3) and those seats are smaller than average. Separate volumes for cargo. Unpractical but nice car.

Fig. 1.11. Honda Civic touring coupe (2017). Length L = 4.492 m, width W =1.878 m, height H = 1.395 m, wheelbase WB = 2.700 m, front/rear axle track AT = 1.547/1.563 m and no-load/load ground clearance GC = 125/105 mm.

1.10.5 Hatchback

A hatchback (for example, see figure 1.12) is a car body configuration with a rear door that swings upward to provide access to a cargo area. This style cars are available in three- or five-door configuration. When it comes to cars, the definition of a door covers more than just the openings at the side. And so most cars have an odd number of doors. Three-door vehicles have two front doors and the boot. The rear seats can often be folded down to increase the available cargo area. These are small cars which would serve 5 people.

Fig. 1.12. Volkswagen Golf GTI (2017). Length L = 4.268 m, width W = 1.790 m (2D) or 1.799 m (4D), height H = 1.442 m, wheelbase WB = 2.631 m, front/rear axle track AT = 1.538/1.516 m and ground clearance GC = 128 mm.

1.10.6 Station Wagon, Estate

A station wagon (for example, see figure 1.13), also called an estate car or simply wagon or estate. In the US this car is called a station wagon. The Brits call it an estate car. The name for the car apparently stems from the car's early use which was to transport people between train stations and its resemblance to horse-drawn wagons used for this purpose. It is an automotive body-style variant of a sedan or saloon with its roof extended rearward over a shared passenger or cargo volume with access at the back via a third or fifth door. The rear seats can often be folded down to increase the available cargo area. The versatility is heavier than the equivalent sedan, which adversely affects the dynamics and economy of the car. It's more of a family car. Note: Station wagons and hatchbacks are similar cars, but station wagons are significantly larger than hatchbacks.

Fig. 1.13. Volkswagen Passat Estate (2017). Length L = 4.767 m, width W = 1.832, height H = 1.516 m, wheelbase WB = 2.791 m, front/rear axle track AT = 1.584/1.568 m and ground clearance GC = 145 mm. Note: Volkswagen Passat is manufacturing in two body types: Estate (Wagon) and Saloon (sedan). Estate (wagon) type also is named as Variant with more comfort or as Alltrack, in which ground clearance is higher and has ability 4×4 drive.

1.10.7 Multi-purpose vehicle

Van, Minivan (for example, see figure 1.14), MPV (multi-purpose vehicle) or MUV (multi-utility vehicle). Most minivans are designed to carry seven (7) passengers. Van - a box shaped vehicle used for transporting goods or people. Minivan is a small van, typically one fitted with seats in the back for passengers which is designed primarily for passenger safety and comfort. It's usually set up for family use, with room for five or more passengers.

Fig. 1.14. Volkswagen Sharan (2017-2018). Length L = 4.854 m, width W = 1.904 m, height H = 1.720 m, wheelbase WB = 2.920 m, front/rear axle track AT = 1.571/1.617 m and ground clearance GC = 152 mm.

1.10.8 Sport Utility Vehicle (SUV)

Sport Utility (for example, see figure 1.15) Vehicle (SUV) traditionally uses the chassis of a truck and use a body on frame design. It can be fabricated unibody (integrates the frame into the body). SUV is very heavy with four-wheel drive system. It is not as fuel efficient as other types of vehicles. There are many reasons why SUVs have become popular. One reason is the comfort of their large cabins. Many models can carry almost as much as a minivan. Another reason is the driver sits higher than other cars, giving better all-round vision. Their size gives them an impression of safety.

Fig. 1.15. Range Rover Sport (2019). Length L = 4.879 m, width W = 2.073 m, height H = 1.803 m, wheelbase WB = 2.923 m, front/rear axle track AT = 1.692/1.686 m and standard/off-rode ground clearance GC = 213/278 mm.

1.10.9 Crossover, Crossover Utility Vehicle (CUV)

A Crossover or Crossover Utility Vehicle (CUV) is mostly based on a passenger car platform, Crossovers use unibody architecture, meaning the body and frame are one piece. The crossover has a smaller frontal cross-section for improved aerodynamics. It also can include all (four)-wheel drive system. A crossover is a vehicle with SUV styling features. Crossovers have ride, handling, performance and fuel economy characteristics similar to passenger cars and are only intended for light off-road use. The Mitsubishi ASX is fabricated on a Mitsubishi Outlander compact SUV base, see figure 1.16.

Fig. 1.16. Mitsubishi ASX (2018). The Mitsubishi ASX is a compact crossover vehicle. In Europe it is sold as the Mitsubishi ASX, and as the Mitsubishi Outlander Sport in the United States. According to Mitsubishi, the letters ASX stand for Active Sports, with X signifying the car's status as a crossover vehicle. Realization 2WD (front) or 4WD. Length L = 4.365 m, width W = 1.810 m, height H = 1.640 m, wheelbase WB = 2.670 m, axle track AT = 1.545 m and ground clearance GC = 205 mm. Note: Parameters presented for car with 18-inch tires.

1.10.10 Pickup truck

A pickup truck (for example, see figure 1.17) is a light-duty truck having an enclosed cab and an open cargo area with low sides and tailgate. The name pickup was derived from its use as a vehicle to haul and transport heavy loads. The first popular pickup truck was the Ford with a pickup body. Over the years, as the pickup truck evolved, it was referred to as a half-ton truck. Pickups are made out of two pieces: a cab and a cargo bed, laying on a strong chassis, derived from trucks. There are various modifications, such as a double cab or a covered load compartment.

Fig. 1.17. Mitsubishi L200 (2018). Length without/with bumper L = 5.205/5.285 m, width W = 1.815 m, height H = 1.780 m, wheelbase WB = 3.000 m, front/rear axle track AT = 1.520/1.515 m and ground clearance GC = 205 mm. For L200 three types exists, Single cab, Club cab and Double cab. Note: Parameters presented there are for Double cub for higher class from Titan. For other modifications dimensions are similar.

1.10.11 Luxury vehicles

Luxury vehicles have an increased level of comfort. These cars are supplied with higher level equipment. Manufacturers declare that this type of vehicle has a better quality than conventional cars. Naturally, they are also more expensive.

The term luxury is subjective and may support either the quality of the car or the brand image of its manufacturer. Luxury brands are considered to possess a better status than premium brands. However, there's no fixed differentiation between the two types of cars. Traditionally, luxury cars are large vehicles. However, at present luxury cars range in size from compact cars to large sedans and SUVs.

Few samples of luxury cars: Mercedes S-Class, Range Rover, Roll-Royce Phantom, Bentley Continental GT, Porsche Panamera, BMW 7 Series, Audi A8, Bentley Bentayga, Jaguar I-Pace, Lexus LS.

BMW, Porsche or Mercedes-Benz recognizes these cars as a logo of luxury status. However, there have been high changes in recent years. Previously the features that where made a car considered as luxury are now standard features on most models. For Luxury vehicles the insurance and maintenance are costlier too [1.72-1.73].

1.11 Car tire labelling and parameters

The tire and rim assembly are an air chamber, which supports the weight of the vehicle when inflated to the proper pressure. The tires also work in the conjunction with the suspension system. They are helping to absorb the shock of road roughness. The properly maintained tires provide a comfortable and safe ride.

Proper tire inflation and maintenance is critical to the safe driving of your vehicle. It also improves fuel economy, reduce exhaust emissions and extend tire life. It is important for better vehicle handling and car stability on the road. Other regular maintenance procedures such as balancing and control of tires pressure is important too. Now the tire pressure monitoring system controls and warns the driver about the lack of air pressure in the tire of the modern car [1.74].

1.11.1 Car tire label

The Tire Label is a mark for tires. In the European Union was introduced a law that manufacturers of tires must declare fuel consumption, wet grip and noise classification of each tire sold in the EU market. This requirement started in November 2012. You can decide what tire to bay. New, good quality tires hold your car on the road, save fuel and reduce noise and emissions. Also, good tires are important for braking and especially on a slippery road. Labels are displaying tire classes (ratings) for fuel efficiency, wet grip and noise.

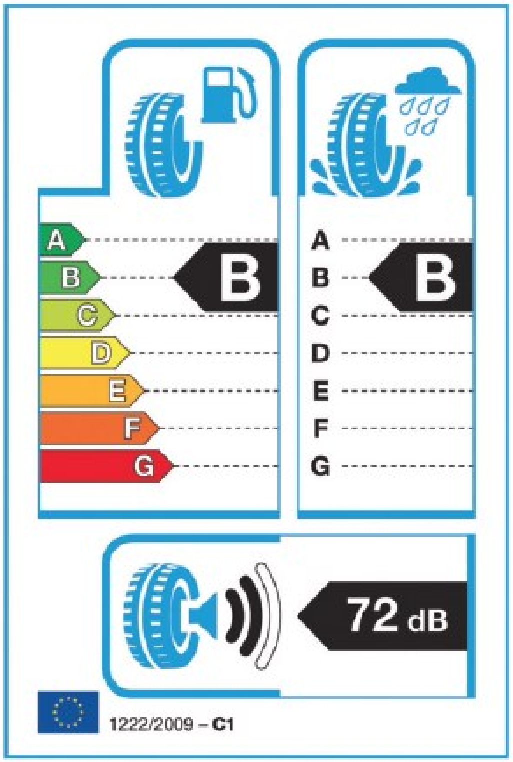

Fig. 1.18. The EU tire label. Left position is Fuel efficiency class. Right position is Wet Grip class. Bottom position is External rolling noise.

The EU has introduced a labelling scheme from 1 November 2012. Document named REGULATION (EC) No 1222/2009) helps consumers to choose the best tires in terms of fuel efficiency, wet grip and noise [1.75,1.76].

Tires for cars and light commercial vehicles must have a sticker on them with product information. The EU tire label are displayed as a sticker on all new tires, see Fig. 1.18.

Left position, Fuel efficiency class. Even though the results may vary according to vehicles and weather conditions. The difference between class G and class A can reduce fuel consumption near 5-10 %.

The fuel efficiency classes from top to bottom distributed as:
A (green color) is highest fuel efficiency class
G (red color) is lowest fuel efficiency class

Right position, Wet Grip class. The braking may vary according to the vehicles, weather and road conditions, however full braking distance may be different between class F and A tires, for A class tires the braking distance is shorter.

Wet grip is classified from A to F:
A is highest class;
F is lowest class;
D and G are not used for passenger cars.

Note: Tires will no longer be allowed in classes F and G for rolling resistance and for wet grip, new scale has only 5 classes from A to E. **New tire Regulation (EU) 2020/740** starts from 1 May 2021 [1.77].

Bottom position. External rolling noise, it's the measured value is in dB (decibels) It is presented in logarithmic scale: 3 dB means 2 times, 6 dB means 4 times).

Noise generated by driving is divided into 3 classes C1, C2, C3 and shown as a sound wave symbol. For C2 class normal tire (2 black waves) European limits is 72 dB. Near or more than 80 dB can cause health problems.

1 black wave: Low noise (3dB or more below the European limit).
2 black waves: Moderate noise (between the European limit and up to 3dB below).
3 black waves: Noisy (above the European limit).

1.11.2 Car tire code

Automobile tires are described by an alphabetic and numeric combination tire code. It is commonly marked into the sidewall of the tire. This code specifies the dimensions of the tire. The load-bearing ability, and maximum speed limitations may be decoded as well. Sometimes the inner sidewall contains additional information.

The tire has a code (See Table 1.4) marked into their sidewall which allows you to understand their technical capabilities. This code provides information on tire size, construction (e.g. radial), its load capacity and its speed rating. We will try to explain how to understand main of tire sidewall information. Also, on sidewall you can find another information: tire brand name, manufacturing date, application conditions (summer, winter) and so on. Tires made in the United States have the DOT serial number located on the inside sidewall near the rim. The letters DOT are followed by eight to thirteen letters and/or numbers. That identify where the tire was manufactured, tire size, the manufacturer's code and date when tire was manufactured [1.78].

The industry standard is to change tires as it became 10 years old. Some tire companies recommend replacement as early as six years after manufacture. It depends on operation conditions. If you use different tires in summer and winter, operation time is longer, of course.

Table 1.4. Example of the tire a code system.

Tire Code: P225/55 R18 98V						
Tire type	Tire width, mm	Aspect ratio, %	Internal construction	Rim (Wheel) diameter, inch	Load index	Speed rating
P	**225**	**55**	**R,** radial	**18**	**98**	**V**

If the code letter is a P on the sidewall, it signifies the tire is for the passenger car. LT means tire is for Light Truck, ST for Special Trailer and T stands for Temporary tires.

1.11.3 Car tire parameters

We will list certain tire parameters, which one part may be read on tire sidewall and other part may be calculated. Simple speaking, a wheel is a round object with a hub and an axle. The tire is the rubber part of a wheel. In an automobile, the wheels of a a car consist of the rims and the tires.

Tire Width. This is the width across the widest point of the tire and is measured in millimetres.

Aspect Ratio. The aspect ratio is the relationship of the tire's sidewall height to its width expressed in percentage.

Internal Construction or Radial. The **R** indicates that the tire's internal construction is radial. Radial tires contain belts of steel fibres that go around the circumference of the tire. Most tires on the road today have a radial construction. Note: Commonly exist B-basic, D-diagonal and R-radial tires. Radial tires are: Flexible sidewalls, reduced fuel consumption, less rolling resistance, a softer ride, more stable contact with the road, more expensive.

Rim diameter. This number indicates the rim (wheel) size in inches, that the tire will fit. The definition of wheel diameter is the distance, in inches, measured across the face of the wheel, from bead seat to bead seat. Note: The term wheel also is used as rim with tire and may be used as rim without tire, a little confusion. What it means, requires see in context.

Tire circumference. Calculating circumference means finding the distance around a circle. To find a tires circumference, you first measure the diameter, or distance across the tire at its centre (radius).

Revolutions per kilometre indicates the number of times a tire revolves while it covers the distance of one kilometre.

Load Index and Speed rating will be presented below.

In Fig. 1.19 shown wheel photo and tire size parameters. In Table 1.5 presented example of tire dimensions and calculated parameters.

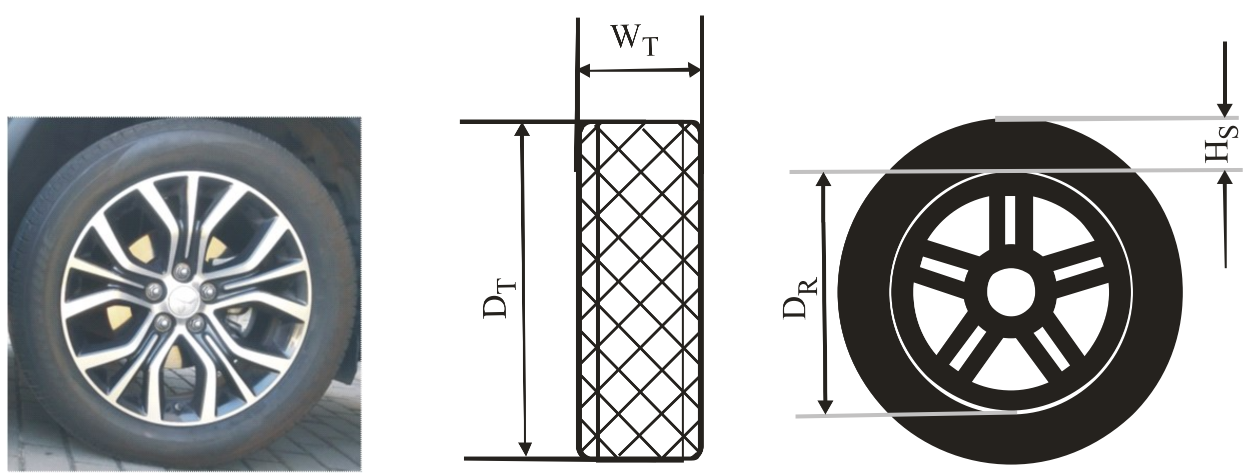

Fig 1.19. Wheel photo (left). Tire dimension symbols attribution scheme (right). Definitions of symbols are presented in Table 1.5.

Table 1.5. Example of tire dimensions and calculated parameters.

Tire: 225/55 R18			
Parameter	Symbol	Relation	Dimension
Tire width	W_T		225 mm
Aspect ratio	AR	AR = $(H_S / W_T) \times 100$	55 %
Rim diameter	D_R	1 inch = 25.4 mm	18 inch = 457 mm
Sidewall height	H_S	$H_S = W_T \times AR/100$	124 mm
Tire diameter	D_T	$D_T = D_R + 2\times H_S$	705 mm
Circumference	L	$L=\pi\times D_T$, π=3.14	2214 mm
Revolutions per km	N_R [rev/km]	N_R = 1/L [km]	452 rev/km

Note: You may find in Internet tire size various calculators, for instance, one of them in [1.79].

1.11.4 Car tire load index and speed rating

The load index and the speed rating information may be found on your tire's sidewall, listed after the tire size information. Tire load index is an assigned number that corresponds to the maximum weight that a tire can support when properly inflated. The higher the tire's load index number, the greater its load carrying capacity. Choosing a tire with a lower load index than the original equipment specifications means that the tire will not carry the load capacity of the original. Most passenger-car tire load indexes range from 75 to 100, but some are higher. Part of Load indexes presented in Table 1.6.

Table 1.6. The tire load index [1.80, 1.81].

Load Index	Mass, kg	Load index	Mass, kg
75	387	88	560
76	400	89	580
77	412	90	600
78	425	91	615
79	437	92	630
80	450	93	650
81	462	94	670
82	475	95	690
83	487	96	710
84	500	97	730
85	515	98	750
86	530	99	775
87	545	100	800
Note: Install tires with a load index as manufacturer recommended. Load index indicates load per tire. For four tires you can load four times higher mass including car weight, passengers and cargo. The load index information may be found on your tire's sidewall, listed after the tire size information.			

The speed rating of a tire indicates the speed category (or range of speeds) at which the tire can carry a load under specified service conditions. The speed rating system used today was developed in Europe in response to the need to control the safe performance of tires at standardized speeds. A letter from A to Z symbolizes a tire's certified speed rating, ranging from 5 km/h to above 300 km/h. This rating system, listed below, describes the top speed for which a tire is certified. It does not indicate the total performance capability of a tire. Part of Tire speed rating indexes presented in Table 1.7.

Table 1.7. Tire speed rating [1.80. 1.81].

Speed Rating	Speed, km/h	Comment
L	120	Off-Road & Light Truck Tires
M	130	Temporary Spare Tires (full size)
N	140	
P	150	
Q	160	Winter Tires (also studded)
R	170	Heavy Duty Light Truck Tires
S	180	Family Sedans and Vans
T	190	Family Sedans and Vans
U	200	
H	210	Sport Sedans and Coupes
V	240	Sport Sedans, Coupes and Sports Cars
W	270	Exotic Sports Cars
Y	300	Exotic Sports Cars
Z	Over 240	Sports Cars

A speed rating Z can mean different things. It may be additional symbol and mean a high-performance tire for high-performing sports cars. Automotive industry adds W- and Y-speed ratings to identify the tires that meet the needs of vehicles that have extremely high top-speed capabilities. The speed rating information may be found on your tire's sidewall, listed after the tire size information.

The recommended tire pressure is most commonly listed on sticker inside the driver's door (may be in another place). If there's no sticker on the door, you can usually find the specifications in the owner's manual. Most passenger cars will recommend 2.2 bar (atm) to 2.6 bar (atm) in the tires when they are cold. The average pressure is 2.4 bar (atm). The air pressure depends on model of tire. Also, may be different pressure for front and rear tires, all time it is useful to read your car manual.

Temporary Compact Spare (special) tires are physically shorter and narrower than the vehicle's standard tires and wheels. Their smaller dimensions require they operate at higher inflation pressures than standard tires, typically 4 atm (bar) Special spare tires may only be used up to a maximum speed of 80 km/h. No more than one temporary spare special tire should be used on a vehicle at one time.

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Chapter 2 Engine & Fuel

At present engines in vehicles are built smaller and more efficient than ever. Modern engines are more powerful, with increased efficiency.

It seems, at first sight, that the engines of a car don't change much. This is often not really the case. Engine design is changing. New internal engine mechanisms are being developed. Also, fuel burning efficiency is improving. Engine operation is computer controlled. It's connected to a modern system of sensors and actuators too. The engine doesn't run on its own, but maintains close communication with other car systems like acceleration, braking, driving stability. This achieves optimal fuel consumption and also increases the safety of driving the car, for instance, through traction control system.

All advantages within the smart car are the results of collaboration between scientists and engineers of various fields. Gradually we'll reveal new secrets of the engine and a car altogether.

2.1 Internal combustion engines classification

An engine or motor is a mechanism designed to convert one form of energy into mechanical energy. In vehicles are used few types of engines. The most commonly used are internal combustion engines, for example, see Fig. 2.1. Now, using electric motors in cars is starting. They have already been used extensively in trains, trolleybuses, using electricity from the grid. An internal combustion engine burns a fuel to create heat which is then used to do work. Electric motors convert electrical energy into mechanical rotation.

Fig. 2.1. Mitsubishi ASX engine MIVEC. It takes up a little space in the engine compartment.

Car engines may change in design, but main elements are common to all engines and should be used for engine classification. Engines can be classified in a few ways, such as the number of cylinders, the geometry of the block, or the type of ignition system and fuel used. The two major engine types in use are spark ignition (gasoline/petrol engine, natural gas also used) and compression ignition (diesel engine), which use different types of fuel (#1 - winter and #2).

From the other classification, one type of the engine is an internal-combustion engine with all cylinders aligned in one row. Usually found in three-, four-, six- and eight-cylinder configurations. They have been used in automobiles, locomotives, ships and aircrafts. In aircraft an engine is inverted so that the cylinders pointed downwards below the crankcase. In this case the cylinders do not blocking the pilot's forward view.

Other a V-type engine, or Vee engine is a common configuration for an internal combustion engine. The cylinders and pistons are aligned, in two separate planes. There needs one crankshaft and two camshafts. The Vee configuration generally changes the overall engine length, height and weight compared to an equivalent inline configuration engine. That engine is more complex and its construction needs more details, increasing motor friction losses. Neglecting some imperfections and costs, those configuration engines are widely used for cars, in heavy transport, land machinery, military transport, combat technology and more.

Very interesting is a flat engine, which is an internal combustion engine with horizontally-opposed cylinders. Typically, the layout has cylinders arranged in two sides of a single crankshaft, but they use two camshafts. It is also known as the boxer, or horizontally-opposed engine. In 1897 Karl Benz developed that boxer engine. The system, in which two horizontally-opposed cylinders become one crankshaft was given and another name as contra engine.

More information can be found in the cited references [2.1-2.4]. In the Table 2.1 is presented the classification of internal combustion engines. Engines grouped according fuel type used and according block geometry. Also, the table indicates compression ratio. The compression ratio is the ratio of the volume of the cylinder and the combustion chamber when the piston is at the bottom, and the volume of the combustion chamber when the piston is at the top. The compression ratio determines also air pressure in the combustion chamber (cylinder).

Table 2.1. Car an internal combustion engines classification and compression rates.

<table>
<tr><td>Fuel</td><td>Ignition type</td><td>Compression ratio</td></tr>
<tr><td>Gasoline (Petrol)</td><td>Spark</td><td>10:1</td></tr>
<tr><td>Diesel</td><td>Compression</td><td>14:1-22:1</td></tr>
<tr><td colspan="3" align="center">Geometry of block</td></tr>
<tr><td>Engine</td><td colspan="2">Cylinders</td></tr>
<tr><td>Straight or inline engine</td><td colspan="2">3, 4 (most common), 6 cylinders</td></tr>
<tr><td>V-type engine</td><td colspan="2">6, 8, 10, may be more cylinders</td></tr>
<tr><td>A flat engine (boxer or horizontally opposed engine)</td><td colspan="2">4 or 6 cylinders</td></tr>
</table>

Earlier the more cylinders a car had, the greater was its performance. The development of fuel injection systems and turbochargers means cars with fewer cylinders are able to compete with larger engines.

Three-cylinder engines are more used on small cars. Three-cylinder engines produce a specific noise and vibration, which is a result of the odd number of cylinders affecting the engine's balance (personal experience).

Four-cylinder engine is simple and therefore the commonest configuration. Four-cylinder engines are found on a large majority of small to mid-range cars. They are almost always set up in an inline layout. Four cylinders offer a good amount of engine output, and may be made more powerful with the introduction of a turbocharger as for other engines. In our opinion at present it is most optimal engines. It's lightweight, low-oil, with just four spark plugs, only four injectors, no need for a large capacity and heavy battery, in one-word cheap exploitation. These are efficient and powerful enough engines.

Six-cylinder engines are found on high-end performance and sports cars, and are commonly set up in a V or straight engine layout. Historically, six-cylinder engines weren't considered all that powerful, but now, thanks to the turbocharger, they're fitted to some of the world's most powerful cars.

Eight or more cylinders cars fitted with eight or more cylinders engines usually fall into the supercar category, given their high-power output. They are normally set up in a V layout, hence are used as V6, V8, V10 or more. For passenger cars powerful engines are not very common.

We will overview some selected parts and systems of the engine, which are important in fuel efficiency, and may be controlled mechanically or may be controlled electronically as it is more important.

2.1.1 Camshaft

Every combustion engine is equipped with camshaft which controls intake and exhaust gases. One or few camshafts within the present engines are placed in the head of the engine and are known as overhead. Also exists pushrod engines, and therefore the camshaft on a pushrod engine (use pushrods to actuate the valves) is inside the cylinder block (cam-in-block). At the present this technique is not very popular due to some imperfection.

SOHC means Single Over Head Cam. Only a single cam rod operates the intake and out take valves. It means that there's just one camshaft per header. Inline engines will contain one camshaft. The V-type and flat type engine will contain 2 camshafts. These SOHC engines have 2 valves per cylinder. One camshaft for the exhaust and, therefore, the intake valves.

DOHC means double Head Cam. In this case two cams are placed over head. Each camshaft operates two of the valves per cylinder, one camshaft handles the intake valves, and other handles the exhaust valves. Now there are 2 camshafts per header for inline engines. 4 camshafts are in the case of a V-type or flat engine.

These DOHC engines usually have 4 valves per cylinder. This suggests that it is possible to do more fine-tuning of the engine. So, which engine to go for? SOHC engines are cheaper and easier to maintain, but they do not have such a good performance or do not ensure the high fuel-efficiency that the DOHC does. So, we will say a DOHC is better, but SOHC is cheaper [2.5]. Scientists and engineers are trying to find ways to implement the camless engine. Maybe its idea realizes in the future [2.6, 2.7].

2.1.2 Gasoline (Petrol) fuel injection

In principle injections systems for gasoline (petrol) and diesel engines are different. Petrol engines require spark ignition system, diesel engines are self-detonation system. Pressure of the fuel mixture with air in diesel engine is twice higher than in petrol engine. Consequently, injectors and operation processes of engines are different.

Gasoline (petrol) engine previously used carburettor fuel system. Many todays cars are using gasoline injection systems, for instance, see Fig. 2.1. That injection systems can be divided in two groups: direct and indirect injection. More popular and simple are indirect systems, which, in turn, may be grouped in two categories. First, Single-point injection (SPI) uses a single injector at the throttle body (the same location as was used by carburettors). Second, Multi-point fuel injection (MPI) injects fuel into the intake ports just upstream of each cylinder's intake valve. Also, it called port fuel injection (PFI) system. MPI systems can be sequential, without rigorous controls. However, at present are used computerized injection systems. Typical fuel pressure is low, only few atmospheres, usually about 3 - 4 atm.

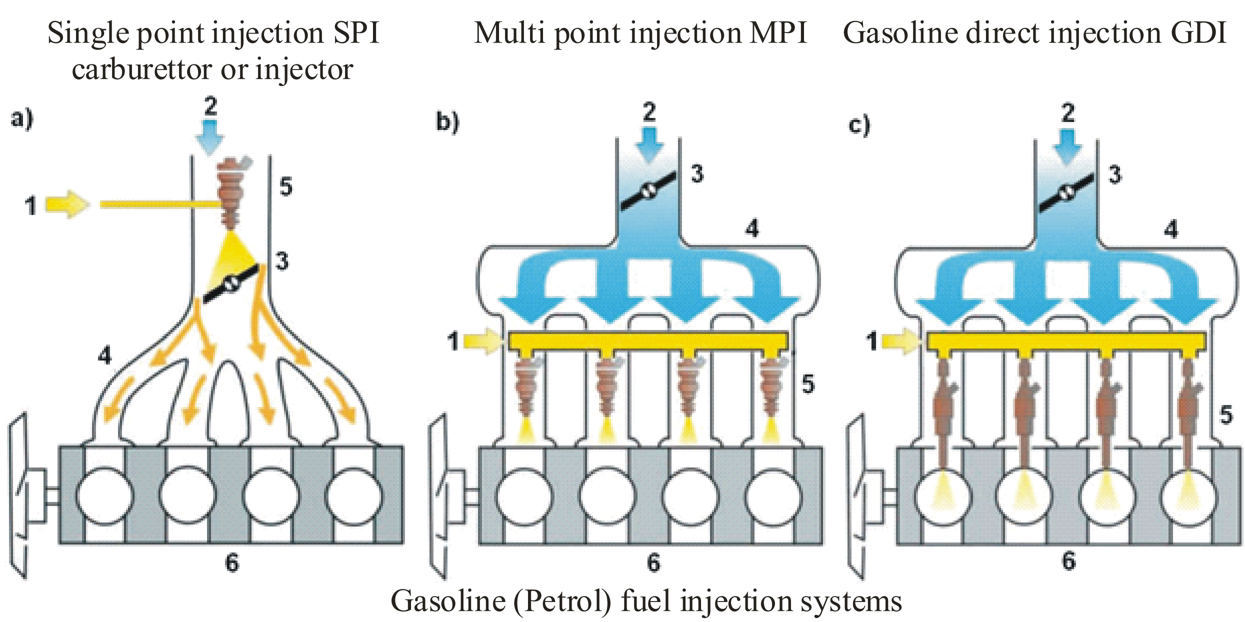

Fig. 2.1. Schematic presentation of various Gasoline (Petrol) Fuel injection systems. a) Single point injection (SPI), b) Multipoint injection (MPI), c) Gasoline direct injection (GDI). 1 means fuel supply, 2 - air intake, 3 - throttle, 4 - intake manifold, 5 - fuel injectors, 6 - engine. In part a) number 5 marks one injector (previously in this position was used carburettor). Adapted from [2.8].

Some a part of today's cars is with installed Gasoline Direct Injection (GDI) system. A system was developed to extend fuel economy. The fuel is injected directly into each cylinder. The system requires high fuel pressure (used two pumps low and high about 50 atm) [2.9]. In a sense a GDI engine is like a diesel engine but with spark plugs. In diesel engine fuel ignite under high compression (auto igniting). GDI engine has spark plugs as all petroleum engines. That is the most difference between GDI and diesel during which doesn't require spark plugs.

Direct gasoline fuel injection systems begin use in aero-engines of about in middle of previous age. Acronym GDI is said with Mitsubishi gasoline direct injection engine. Different companies used different acronyms for this technique. The injectors are exposed to more heat and pressure. So more costly materials and higher-precision electronic management systems are required [2.10 - 2.12]. So, direct fuel injection system costs more than indirect injection system.

Computerized injection systems are new application region for car gasoline engines. This is a rapidly developing area. All modern vehicles today use computerized fuel injection system systems, MPI or GDI, to provide fuel to each cylinder of the engine individually. Computer controls allow the engine to work at peak efficiency in all situations. It allows the vehicle to start out right up. It is no problems on cold days to start an engine as well.

Fuel injection systems results in: Best fuel to air ratio for every cylinder; Higher engine power output; Greater fuel efficiency; Eliminates evaporation of fuel; Possible control of consistence of exhaust gas; Generates much lower emissions.

2.1.3 Diesel engine common rail direct injection (CRDI) system

All diesel engines use fuel injection by design [2.13]. Most diesel engines have fuel injected into the combustion chamber. There are three common architectures of diesel fuel injection systems: Pump-Line-Nozzle (high pressure fuel spraying into the cylinder via the nozzle of an injector) system, Unit Injector system and Common Rail direct injection system.

Throughout the early history of diesels, they were always used a mechanical pump to inject fuel for each cylinder. Fuel lines were separated and in all cylinders were installed individual injectors.

Most modern diesel engines use common rail direct injection (CRDI) systems, for example, see Fig. 2.2. Fuel system include low pressure supply circuit low pressure pump and high-pressure delivery circuit with high pressure fuel pump. High pressure fuel is supplied through bus, to which parallelly installed electronically controlled injectors for each cylinder. The high pressure depends on injector type: for injectors with solenoid valves requires over 100 atm. New-generation common rail diesels with piezoelectric injectors requires pressure up to 2500 atm (more pressure, better fuel atomization).

Injection pressure is proportional to engine speed. This typically means that the highest injection pressure can only be achieved at the highest engine speed and the maximum achievable injection pressure decreases as engine speed decreases. This relationship is true with all pumps, even those used on common rail systems [2.15-2.17].

Petrol-injectors are quite different in construction and size in comparison with the diesel-injectors. In a petrol engine, the fuel and air are mixed with each other a long time before they are transported into the cylinder, whereas in a diesel engine, the diesel fuel injector quite literally injects the fuel directly into the cylinder, where it then combines with the air. The diesel system is more expensive than petrol injection system. High pressure diesel fuel pump is very expensive.

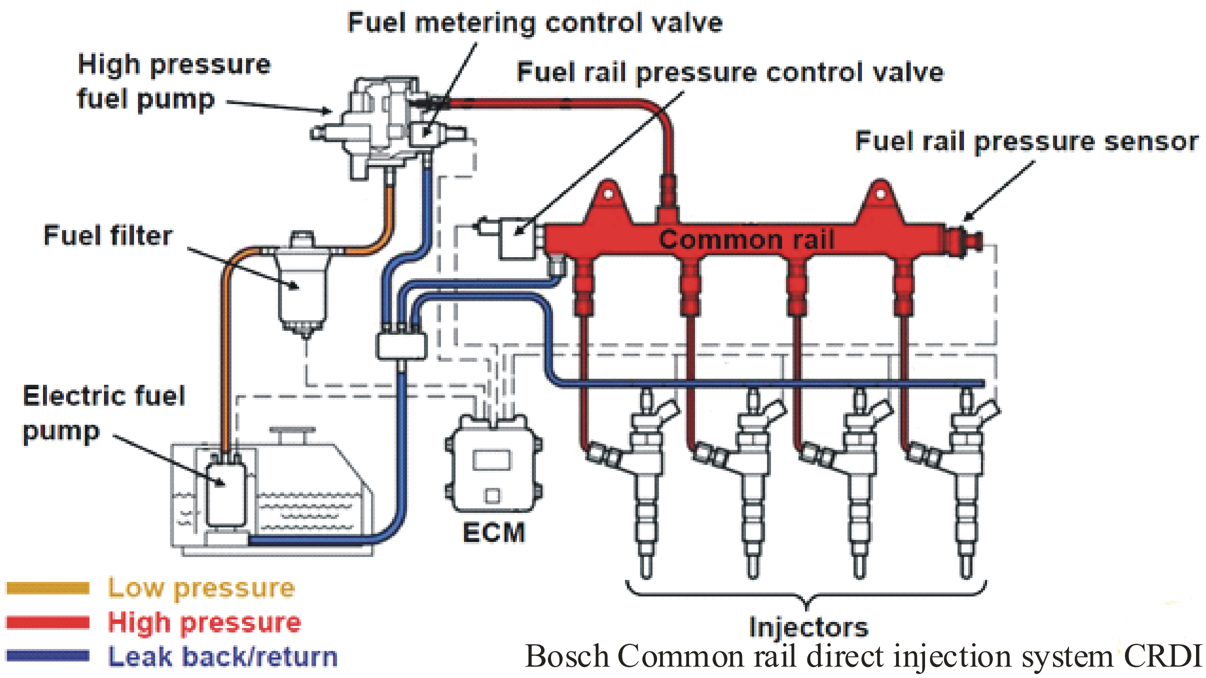

Fig. 2.2. Common rail diesel fuel injection system (Bosch). Adapted from [2.14].

2.1.4 Gasoline (petrol) injectors

We give multi point injection system which is more commonly utilized in internal-combustion engine. Example of this technique see in Fig. 2.3. This technique doesn't require high pressure pump. For a gasoline internal-combustion engine, fuel pressure typically is within the range of 3 - 4 atm.

Fuel injectors are connected to the rail, but their valves remain closed until the engine control unit decides to send command. Then the injector is energized, an electromagnet (solenoid) moves a plunger that opens the valve, allowing the pressurized fuel to squirt out through a small nozzle. For instance, the design of petrol fuel injector is shown in Fig. 2.4. The nozzle is designed to atomize the fuel - to form as fine a mist as possible in order that it could burn easily.

All injectors are controlled individually. Opening moment and duration of spray depend on collected information in computer. It helps to achieve more power and more efficiency of the engine.

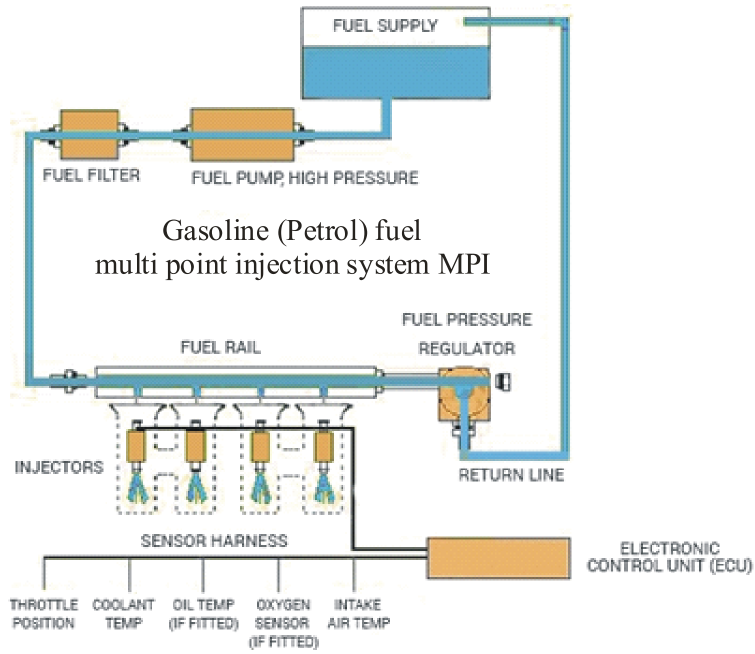

Fig. 2.3. Gasoline (Petrol) fuel Multipoint injection system. Adapted from [2.18].

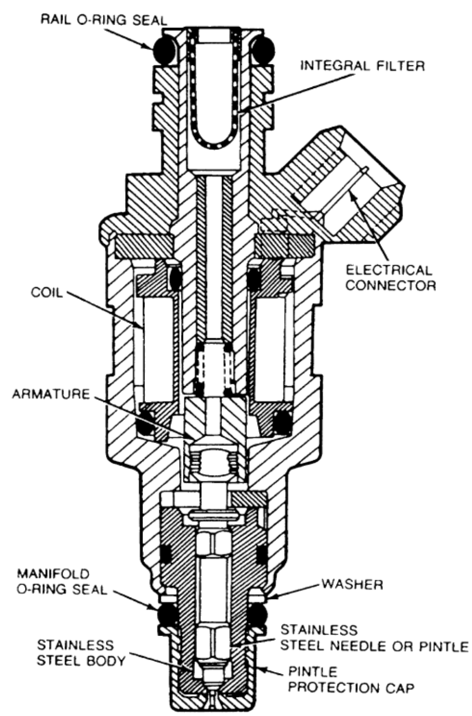

Fig. 2.4. Electronically controlled gasoline engine solenoid type fuel injector construction. Coil is solenoid and it works as electromagnet. It is controlled with electric current. Adapted from [2.19].

2.1.5 Diesel engines injectors

Diesel fuel pump and injector may be combined in one Unit Injector (UI) system. There are few types of diesel engines injectors commonly named as Unit Injector. First is named as Electronic Unit Injector (EUI) and second is named as Hydraulically Actuated Electronic Unit Injector (HEUI) [2.20]. Unit Injector merges the functions of an injector-nozzle and the injection pump into one unit. This design consists of an individual pump assigned to each cylinder rather than a common pump used for all cylinders in earlier generation models. In this system, the pump and nozzle are merged into a single compact assembly which fits directly on the cylinder head. Very simple system may achieve high pressure in unit injector. An engine camshaft mechanically drives the injector typically through the rocker lever and pressurizes fuel.

An electronically controlled unit injector is a unit injector with electronic control. The EUI utilizes an electric solenoid activated poppet valve to meter fuel. Closure of the solenoid valve initiates pressurization and injection and opening of the valve causes injection pressure decay and end of injection. The pressurized delivery of fuel is camshaft-driven, but the timing of the injector's internal operations is controlled by the engine control unit so as to achieve certain advantages. The HEUI uses engine lubrication oil to pressurize fuel.

Most popular is Common-rail direct fuel injection system for diesel engines, which uses a high press fuel pump. On diesel engines, it features a high-pressure fuel rail feeding solenoid valves of injectors, which construction is presented in Fig. 2.5. The needle valve is controlled precisely by a pressure-sensitive spring. Valve lifts needle while fuel in cylinder is required. The nozzle has extremely critical tolerances. The clearance between its moving parts is barely 0.002 mm or 2 microns. At present the diesel is injected by through 0.25 mm^2 size hole. The injected fuel quantity can vary from 1 mm^3 to 350 mm^3.

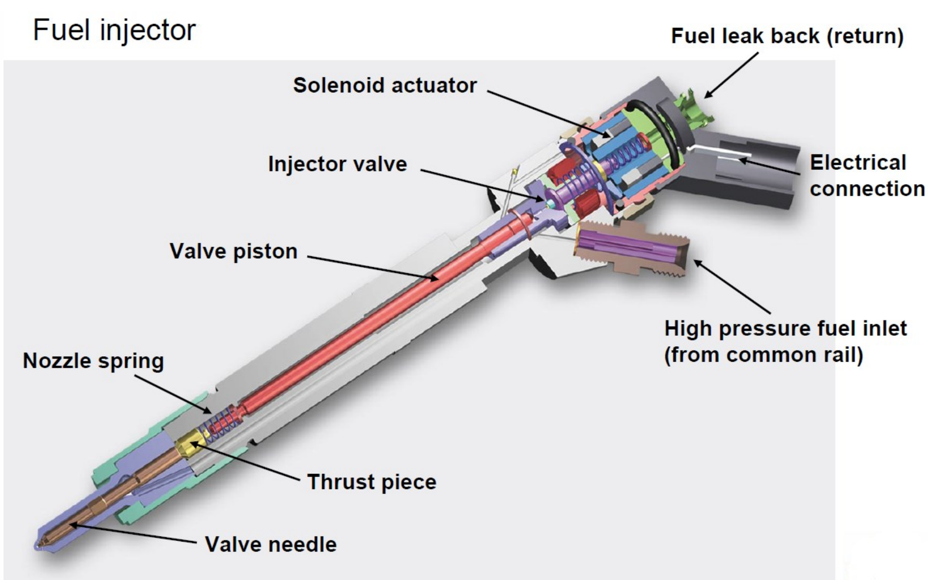

Fig. 2.5. Electronically controlled solenoid type fuel injector for common rail direct injection system. Solenoid actuator controlled with electric current. Adapted from [2.14].

The most advanced type of injectors in the common-rail direct fuel injection systems are the Piezoelectric injectors [2.21-2.23], for instance, see Fig. 2.6. They not only provide increased precision for the latest generation of CRDI engines but also may create fuel pressures up to 3000 atm. Very high pressure used for good fuel atomization, it also increases the efficiency of the engine, realizes high output power and torque, lower gas emissions.

These modern piezoelectric fuel injectors work on the Piezoelectric principle. Piezoelectric material, such as quartz, change dimensions depending on electric field strength. A Piezo actuator consists of hundreds of small piezoelectric crystals which are stacked one above the other in the injector. When electrically charged, piezo crystals can change their structure in just a few thousandths of a second by expanding slightly. This expansion of the stack results in its linear movement and transmit injector needle. As a result, the injectors open/close within a few milliseconds (thousandth of a second). Therefore, it can inject a very small amount of fuel, weighing less than one-thousandth of a gram.

Solenoid valve injectors controls with pulsed current of the order of 5-20 A, piezoelectric injectors controls with pulsed voltage of the order of 200 V.

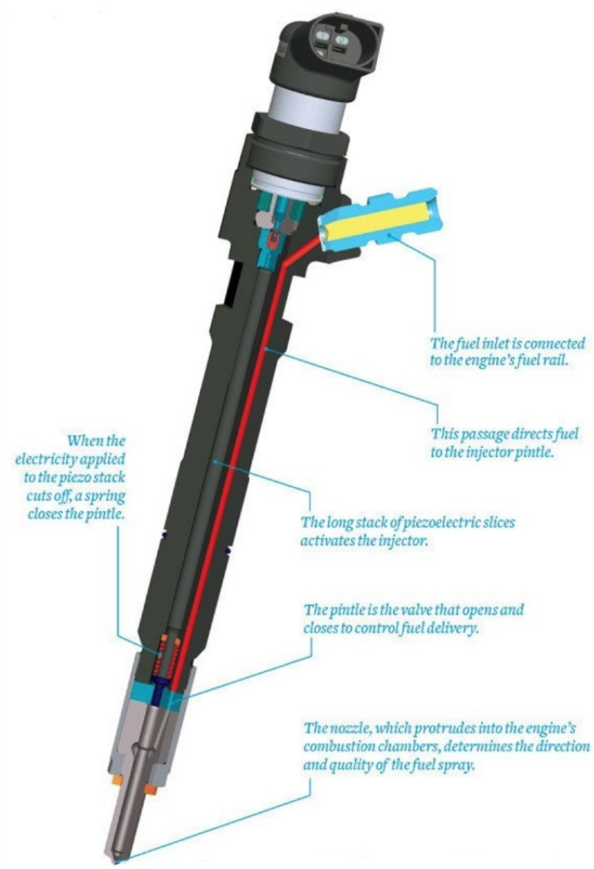

Fig. 2.6. Electronically controlled piezoelectric-type fuel injector for common rail direct injection system. It is controlled with electric field. Adapted from [2.23].

2.1.6 Turbo charger

Some diesel and also petrol engines are equipped with turbo systems. Turbocharger, or turbo, is rotating a gas compressor. The turbo (turbo charged) systems are used to achieve more power in engine. The turbocharged engine will put out more horsepower than the normal traditional engine. Purpose of turbocharging, is getting more horsepower from a smaller engine than equivalent to that of larger engine. A turbocharger is a form of supercharger. It increases the amount of air entering the engine to create more power. More air – more fuel.

A turbocharger has the compressor powered by a turbine. The turbine is driven by the exhaust gas from the engine. The difference between the two devices is their source of energy. Turbochargers are powered by the mass-flow of exhaust gases driving a turbine. Superchargers are powered mechanically by belt- or chain-drive from the engine's crankshaft. Exists information that in future may be used an electrically driven turbocharger.

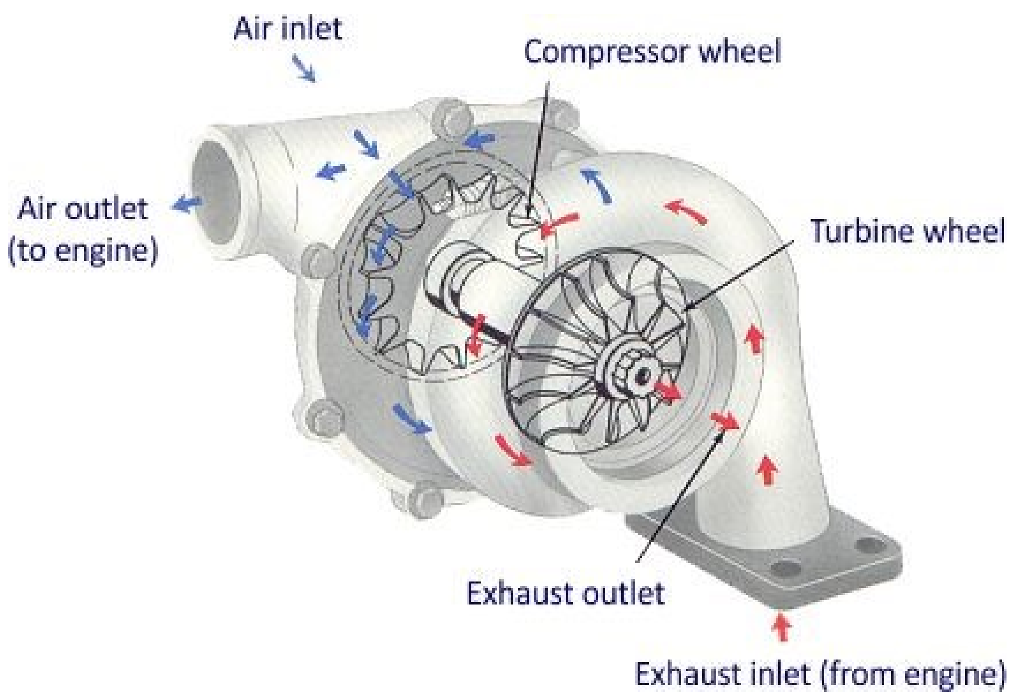

Fig. 2.7. Turbocharger design and flow of inlet (blue arrows) and exhaust gases (red arrows). Adapted from [2.24].

The turbine in the turbocharger spins at speeds of up to 150 000 rotations per minute (rpm) - that's about 30 times faster than most car engines camshaft rotates (5000 rpm). Temperatures in the turbine are also very high.

A turbo charger is more efficient than a supercharger. A turbo charger is not connected directly to the engine, it can spin much faster than a supercharger. When the pressure of the engine's intake air is increased, its temperature also increases. With more pressure being added to the engine through the turbocharger, overall temperatures of the engine will also rise. To stop the temperature rise, turbocharger units often use of an intercooler. May be used air-to-air or liquid-to-air intercoolers. The turbocharger operates at high temperatures and in aggressive gas environments. Therefore, the whole system must be made of a special alloy, which raises the price. The main limitation of the turbocharger is related to Turbo Lag. It is delay in acceleration. When the turbo switches on, you may get a jump in acceleration.

Turbocharger increases the number of parts attached to the engine, and at the same time the engine and a car price too. For more read references [0.23, 2.12. 2.13, 2.25, 2.26].

2.2 Variable valve timing & lift

The traditional engine has one cam profile for the entire revolution range. The variable valve lift (VVL) engine has two profiles: low-lift and high-lift. Under normal conditions, the engine will use the low-lift cam to operate the valves. However, at higher load engine, a solenoid switches in other high position lift. Valves will be opened more and increase the engine performance.

Variable valve timing is used mainly to reduce engine emissions. It allows the engine to change the valve timing using oil pressure actuators. Both systems allow more control of engine power and emissions.

Many modern engines are now equipped with variable valve timing and lift systems [2.27]. That improve the performance of the engine and emissions. Variable valve timing increases an engine's adaptation to various load conditions. In result it is increased fuel economy and engine torque.

Some consumers know the terms like VTEC, VVT-i, VVL or VANOS, but they may not know what these systems do. Various variable valve lifts and timing systems are used in the engines industry. The variable valve timing and lift (VVT, VVL) systems used in the car engines are presented in Table 2.2. Variable valve lift and timing systems involve complex mechanical and hydraulic processes inside the vehicle's engine. Part of them is controlled electronically through actuators such as solenoid type valves. Each manufacturer's variable valve timing system may be slightly different, but most of them functioning on the same basic principles. For more reading see [2.28-2.32].

Table 2.2. Variable valve timing & lift (VVT & VVL) systems of few companies.

Car company References	Variable valve timing/lift (Abbreviation)	VVT/VVL system (Explanation)	Driving/Actuator
Audi [2.33 - 2.35]	AVS	Audi Valvelift System	Electromagnetic solenoid, mechanical
BMW [2.31, 2.36 - 2.39]	VANOS, Double-VANOS, Valvetronic	Variable camshaft timing (variable Nockenwellensteuerung), Variable valve lift system with variable valve timing	Hydraulic pressure Continuously Electric motor, Series of intermediate rocker arms, Continuously

Ford [2.40, 2.41]	VCT Ti-VCT	Variable Camshaft Timing Twin Independent Variable Camshaft Timing	Solenoid, Oil Pressure, Continuous variable cam phasing BorgWarner's Cam Torque Actuation (CTA) system
Honda, Acura [2.42 - 2.44]	VTEC, i-VTEC	Variable Valve Timing and Lift Electronic Control, (intelligent)	Solenoid, valve Hydraulic selection
Hyundai, Kia [2.45 - 2.47]	CVVT Dual-CVVT	Continuous Variable Valve Timing	Vane*, Solenoid Oil Valve
Mazda [2.48, 2.49]	S-VT	Sequential Valve Timing	Hydraulic Pressure Vane* actuator
Mercedes [2.50 - 2.52]	Camtronic	VVT, Cam-phasing actuator VVL, Valve Lift Adjustment, 2-stage system	Oil, Electromagnetic solenoid Electromagnet camshaft adjuster, Lift solenoid. Mechanical sliding
Mitsubishi [2.53 - 2.57]	MIVEC MIVEC Turbo	Mitsubishi Innovative Valve Timing Electronic Control	1. Continuously variable valve timing (hydraulic actuator) for intake or intake and exhaust 2. Continuously variable valve timing & lift (mechanical, electric motor), for intake
Nissan [2.31, 2.58 - 2.61]	N-VTC, CVTC(S), VVL, VVEL	Nissan Variable Timing control, Continuous Variable Timing Control (System), Variable Valve Lift, Variable Valve Event Lift	Hydraulic Pressure, Vane* actuator Continuous, electric motor
Subaru [2.62 - 2.64]	AVCS, i-AVLS	Active Valve Control System, Intelligent Active Valve Lift System	Hydraulic, phase Hydraulic, change cam lobes (two types)
Toyota [2.30, 2.31, 2.36, 2.65, 2.67]	VVT, VVT-i, VVTL-i Valvematic	Variable valve timing Variable valve timing & lift Variable valve timing & lift	Hydraulic phasing actuator. Rocker arm. Controlled oil pressure Hydraulic actuator. Series of intermediate rocker arms. Continuous
Volkswagen [2.68]	VVT	Variable Valve Timing Fluted variators (Phasers)	Continuous, Phase, Hydraulic, Solenoid valves
* Note: Vane is a thin flat or curved object that is rotated about an axis by a flow of fluid.			

2.3 Overview of Variable valve timing & lift systems

Variable valve timing and lift systems (VVT and VVL) change the operation of the engines essentially. They become more controllable, but more complicated too. That systems may be classified as discrete or continuously operating system. VVT and VVL can be conjugate in one unit. Both systems increase fuel economy, decrease exhaust gas emissions, increase power and support constant torque in the wider rotation range of engine, for instance, see Fig. 3.2.

Continuously operating systems are more flexible. Fuel economy is about in the range 4-10%. This economy may be quickly lost in traffic jam or at high speeds. Please, drive intelligently.

2.3.1 Audi valvelift system (AVS)

The Audi valvelift system (AVS), one of the useful innovations of the brand. It regulates the lift of the valves in two stages depending on load and engine speed. The system thus increases torque and parallelly reduces fuel consumption as well. Two versions of the AVS system are available. In the V6 engines in which AVS is used, it acts on the intake valves opening them less or more.

In the latest-generation 2.0 TFSI (Turbo fuel stratified injection) the AVS varies the lift of the exhaust valves. It reduces flushing losses in the combustion chamber, creates the optimal flow of the exhaust gas to the turbocharger if equipped.

System uses so-called cam pieces. They are sliding electromagnetic sleeves on the camshaft [2.33,2.34].

The system actuators are electromagnetic solenoid-type. Two actuators are used per cylinder. One actuator moves the cam element on the camshaft for a large valve lift. The other actuator resets the cam element for small valve lift [2.35].

2.3.2 BMW VANOS, Valvetronic

The name VANOS is derived from the German term "variable Nockenwellensteuerung", meaning variable camshaft control. The double-VANOS system continuously adjusts the camshaft positions for both the intake and the exhaust valves. This results in higher torque at low engine rotations and more power at higher engine rotations. Also, it reduces fuel consumption and emissions. Double-VANOS also controls the amount of exhaust gas that is re-circulated back to the intake manifold, enhancing fuel economy. The Vanos system works at intake camshaft only. However, it can be duplicated at the exhaust camshaft to provide a wider range of adjustment. BMW calls this Double Vanos or Bi-Vanos [2.36, 2.37].

The Valvetronic system is a BMW variable valve lift system which, in combination with variable valve timing, allows infinite adjustment of the intake valve timing and duration. Valvetronic works in conjunction with the independent Double VANOS system, which continuously varies the timing (on both intake and exhaust camshafts).

This system replaces the conventional accelerator. Engine power may be controlled by the lift of the individual intake valves on each cylinder. Also, old accelerator is installed for emergency. Valvetronic uses a stepper motor to control a secondary eccentric shaft. System equipped with a series of intermediate rocker arms; they regulate the degree of valve lift [2.31, 2.38, 2.39].

2.3.3 Ford Ti-VCT

Ti-VCT is acronym Twin Independent Variable Camshaft Timing. The name given by Ford. It is variable camshaft timing system of both the intake and exhaust independently. This allows for improved power and torque at lower engine rotations, and improved fuel economy and reduced emissions as well.

Traditionally, camshafts only have been able to open the valves at a fixed point defined during engine design and manufacturing. But with modern variable cam timing systems, the camshafts can be rotated slightly relative shifted to their initial positions, allowing change the cam timing. This technology applies it to both the intake and exhaust camshafts of the DOHC design engine. Ford Ti-VCT engines use BorgWarner's Cam Torque Actuation (CTA) system to change delay time. Ti-VCT system does not use oil pressure energy to shift rotation angle (phasing) as in traditional VCT, but use the existing torsional energy in the valve train to shift the rotation angle of the camshaft [2.40, 2.41].

2.3.4 Honda VTEC, i-VTEC

VTEC (Variable Valve Timing & Lift Electronic Control) is a system developed by Honda. It may improve the volumetric efficiency of a four-stroke internal combustion engine. Also, higher performance at high rpm, and lower fuel consumption at low rpm is achieved. The VTEC system uses two (or may be three) camshaft profiles. Selection between profiles controls hydraulically. Oil pressure shifts different cam profiles or in other words varies cam profiles. System i-VTEC regulates the opening of air-fuel intake valves and exhaust valves in accordance with engine speeds. The i-VTEC is smarter VTEC system [2.42-2.44].

2.3.5 Hyundai, Kia CVVT, Dual-CVVT

CVVT (Continuous Variable Valve Timing) is Hyundai version of VVT. CVVT is installed on the camshaft and controls intake valve open and close timing. The CVVT changes the phase of the camshaft via oil pressure. The CVVT has the mechanism rotating the vane (a thin flat or curved object that is rotated about an axis by a flow of fluid) type actuator. Hydraulic pressure of oil generates an engine. The pressure controls solenoid. Oil pressure change the intake valve timing continuously.

The Dual Continuous Variable Valve Timing (D-CVVT) has valve timing control of both intake and exhaust valves [2.45 – 2.47].

In Hyundai engines may be installed the CVVD (Continuous Variable Valve Duration) system. It consists of a variable control unit and a drive motor on the camshaft.

2.3.6 Mazda S-VT system

S-VT, or Sequential Valve Timing, is an automobile variable valve timing technology developed by Mazda. S-VT varies the timing of the intake valves by using hydraulic pressure to rotate the camshaft [2.48].

S-VT is a vane (a thin flat or curved object that is rotated about an axis by a flow of fluid) oil actuator.

It continually varies the phase of the intake valve timing and the crank angle. A computer calculates the intake valve timing. According computer commands oil control valve (OCV), regulates the oil pressure. In program are included engine rotation speed, intake volume, water temperature [2.49].

2.3.7 Mercedes CAMTRONIC

Mercedes-Benz designed the new CAMTRONIC, an innovative engine management system that reduces an engine's CO_2 emissions. The new system optimizes fuel consumption. Camtronic was designed in a modular way so that it was possible to adopt the important basic components from the already existing engine. These components are the complete crankcase, the basic cylinder head or the camshaft adjusters. Camtronic consists of two parts VVT and new VVL.

Mercedes Camtronic intake valve lift adjustment being a mechanically-operated system with only an electronically-controlled actuator. Camtronic valve lift is a 2-stage system (noncontinuous).

The intake camshaft is served with a conventional variable cam-phasing actuator at its end as well as the Camtronic variable valve lift components. The camshaft itself consists of an inner carrier shaft and 2 hollow cam-pieces; each serves 2 adjacent cylinders. Each cam has 2 profiles (low lift and high lift). Which of them is engaged, depend on the longitudinal position of the cam-pieces. When the engine needs to switch cam profiles, a centrally-mounted actuator (solenoid) applies steel pins to the grooves on the cam-pieces. The rotation of camshaft causes the cam-pieces to slide in longitudinal direction and engage the alternative cam profiles within one revolution. Camtronic is made to reduce fuel consumption (about 4%) [2.50-2.52].

2.3.8 Mitsubishi MIVEC

MIVEC (Mitsubishi Innovative Valve timing Electronic Control system) is the name of Mitsubishi Motors manufacturer. It is technology intended for control of engines valve timing and lift. The aim of this technology was to achieve high power output, low fuel consumption, and low exhaust emissions. The MIVEC engine was first used in 1992. In 2007 Mitsubishi Motors adopted a system that continuously and optimally controls the intake and exhaust valve timing. Now, the all-new MIVEC engine controls both intake valve timing and amount of valve lift at the same time, all the time.

Part of DOHC engine series uses the continuously variable intake and exhaust valve timing MIVEC. The system continuously and optimally controls the intake and exhaust valve timing according to engine loading conditions. This system delivers high performance and fuel efficiency.

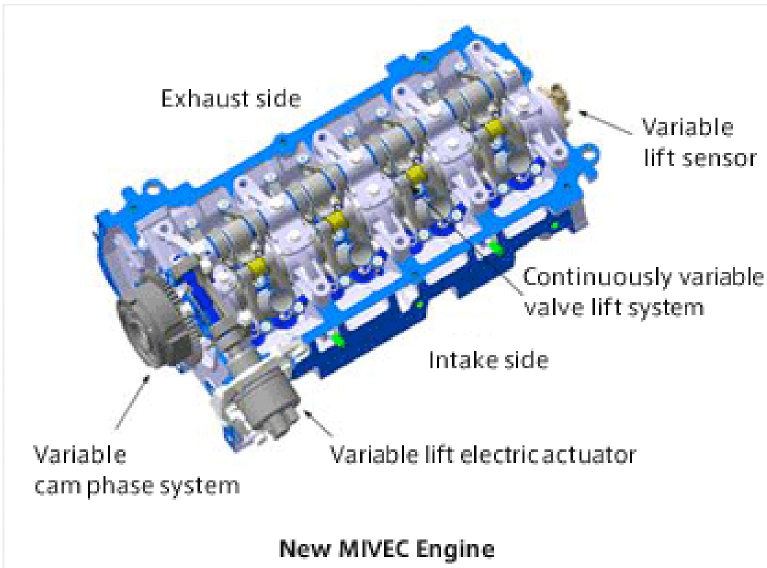

Fig. 2.8. New generation Mitsubishi MIVEC (Mitsubishi Innovative Valve timing Electronic Control) engine construction. Adapted from [2.54].

The mechanism is controlled by hydraulic actuator installed in the intake side and exhaust side camshaft end. The actuators drive oil, which is controlled electronically. Phase shift depends on oil pressure [2.54].

In other DOHC models, the MIVEC engine uses the continuously variable intake valve timing MIVEC system that continuously and optimally controls only the intake valve timing according to engine running conditions [2.55].

Mitsubishi for different car models are used different engines in which are applied different MIVEC combinations, for example:

1) 4A92 Engine type: 4-cylinder, DOHC 16v, ECI (electronically controlled injection) - Multipoint, Displacement=1.6 L (1590 cc), Power: 86 kW; 117 hp at 6000 rpm, Valvetrain: Direct acting DOHC, 16 valves, continuously variable MIVEC intake valve timing. For instance, this engine is used in Mitsubishi ASX.

2) 4B11 Engine type: 4-cylinder, DOHC 16v, ECI (electronically controlled injection) - Multipoint, Displacement=2.0 L (1998 cc), Power: 110 kW; 150 hp at 6000 rpm, Valvetrain: Direct acting DOHC, 16 valves, continuously variable MIVEC intake and exhaust valve timing. For instance, this engine is used in Mitsubishi Outlander.

ASX or Lancer with MIVEC type engine and with Stop-Start system may improve fuel economy up to 12 percent.

In Figs. 2.8-2.10 are shown new generation Mitsubishi MIVEC engine and MIVEC system (VVL and VVT) components.

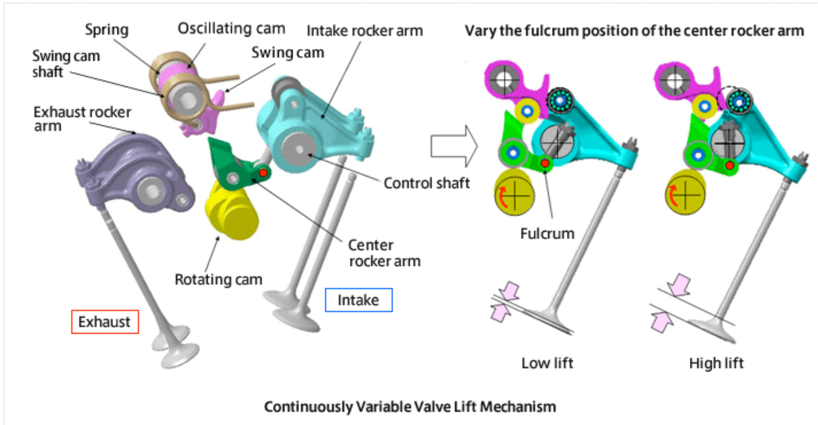

Fig. 2.9. Mitsubishi MIVEC engine's achieves continuous variable valve lift. Adapted from [2.55].

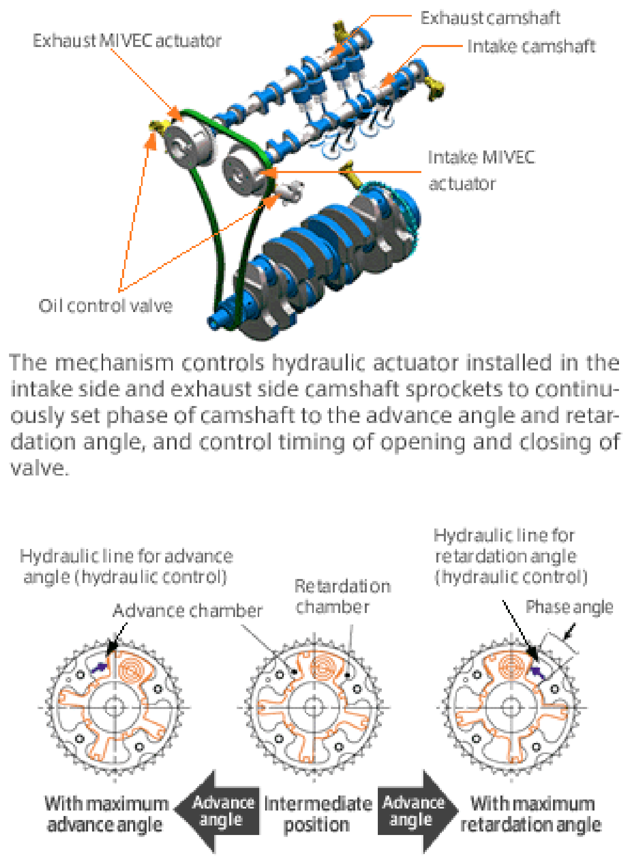

Fig. 2.10. Mitsubishi continuously variable valve timing mechanism. Adapted from [2.55].

2.3.9 Mitsubishi MIVEC Turbo (gasoline engine)

Mitsubishi has started to apply MIVEC system to turbo gasoline engine, see Figs. 2.11, 2.12. On the intake side, Mitsubishi Motors newly developed an intake manifold, and placed an electronically-controlled throttle valve upstream of the manifold. Therefore, a stainless-steel exhaust manifold on the exhaust side was used. Also installed are titanium and aluminium turbo charger downstream of the manifold. Optimized are the shape of the compressor wheel and realized an improved response too. The compressed air pumped out of the turbo charger is cooled in the intercooler and sent to the intake of the manifold. All system was optimized as much as possible [2.56]. This system is used in Mitsubishi Eclipse Cross. In this car may be installed engine 4B40. Type: 4-cylinder, DOHC 16v, MIVEC Turbocharged, Electronically Controlled Injection - Multipoint, Displacement=1.5 L (1499 cc), Power 110 kW (150 hp) at 5500 rpm, Max torque 250 Nm at 2000-3500 rpm [2.57]. For better understanding, compare with engines presented in paragraph 2.3.8 and also see Fig. 3.2 in paragraph 3.1.

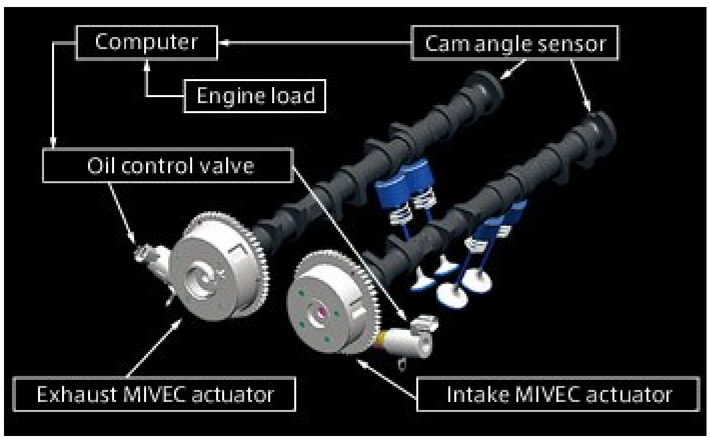

Fig. 2.11. Mitsubishi MIVEC continuously variable valve timing mechanism. Adapted from [2.56].

Fig. 2.12. Mitsubishi MIVEC turbo charger: Titanium alloy turbine wheel and aluminium alloy compressor wheel. Adapted from [2.56].

2.3.10 Nissan N-VTC

Nissan Variable Timing control (N-VTC) is an automobile variable valve timing technology developed in 1987 by Nissan. CVTC(S) is continuous variable valve control (system). System works through hydraulic pressure using vane actuator [2.58].

Nissan introduced the Variable Valve Event and Lift (VVEL) in 2007. Control shaft rotates by electric motor. It has eccentric shape, and it pushes output cam to change the lift of valve [2.31, 2.59-2.61]. The VVEL control logic is complicated. Imagine that a wedge between a valve lifter and a shaft cam is pushed or pulled by a DC motor-driven gear, thus changing the additional lifting height.

2.3.11 Subaru AVCS & i-AVLS

Active Valve Control System, or AVCS for short, is an ECU controlled, hydraulically operated, adjustable camshaft gear. By advancing or retarding the camshaft timing, Subaru engineers can alter the moment the valves opened relative to engine load. This can improve engine power, improve fuel economy, and reduce emissions [2.62].

AVLS (active valve lift system) is one of the keys to the power and efficiency contribution in today's Subaru boxer engines. The letter "i" in the name i-Active Valve Lift System stands for intelligent - meaning the system automatically responds to the driving and atmospheric conditions to deliver optimum performance. The camshafts on an AVLS-equipped engine have specially designed lobes for intake valves. They feature two different cam profiles: A low/mid-lift profile and a high-lift profile. The connection cam profile is regulated by the Engine Control Module (ECM). The AVLS-equipped Subaru engines use oil pressure generated by the engine to activate the different valve lift settings [2.63, 2.64].

2.3.12 Toyota VVT, VVTL, Valvematic

Toyota's VVT-i (Variable Valve Timing - Intelligent) has been expanding to more new Toyota models. Its mechanism is similar to BMW VANOS system. It is also a continuously variable design and uses hydraulic phasing actuator.

However, the word Intelligent emphasizes the smart control program. Not only varies timing according to engine rev, it also considers other parameters such as acceleration, going uphill or downhill.

VVTL-i (Variable Valve Timing and Lift intelligent system) or also named as Variable Valve Timing and Intelligence with Lift) is an enhanced version of VVT-i. System VVTL-i can alter valve lift and duration. Oil pressure controls work of system. Also, system may be applied to both intake and exhaust valves. For more reading see [2.30, 2.31, 2.36, 2.65, 2.66].

The Valvematic is continuous variable valve timing and lift system. The technology made its first appearance in 2007. Lift system uses series of intermediate rocker arms and controls via oil pressure. It controls the valve's open and close timing as well as the amount of lift using computer. As a result, this helps to improve fuel economy, engine output and response, and provides cleaner emissions [2.67].

2.3.13 Volkswagen VVT

Volkswagen (variable valve timing (VVT) system use hydraulically controlled named as floated variators (phasers), one for each camshaft inlet and exhaust. The system is electrically-controlled. Solenoids control oil pressure. The V-type engines have four variators in total, one for each camshaft [2.68]. Hall sensors measure the engine momentary position of the camshafts.

Variable valve-timing systems may use a cam phaser that rotates the position of each camshaft relative to the timing chain. The cam phaser has two basic components: an outer sprocket connected to the timing chain and an inner rotor (connected to the camshaft) that varies the valve timing by adjusting the rotation angle of the cam.

This inner rotor consists of a set of lobes, and oil fill the spaces (chambers) between the outer housing and the lobes. Inner rotor may spin at the same rate as the outer housing. If it is oil filled to one side of the lobe then it is removed from the other. The rotor turns at a certain angle to the stator. Getting shift in phase, it realizes VVT. Most systems use pressure to push the rotor forth and back. Volkswagen cam phaser consist of the rotor inside the cam phaser which changes position when oil pressure is routed into the chambers. This rotates the cam to change valve timing. In other words, a cam phaser is just an adjustable camshaft sprocket that can be turned by means of a computer-controlled servo.

2.4 Common rail direct fuel injection systems in diesel engines

Diesel-powered cars pollution initiates a hot debate. However, diesel engines are still in the mainstream of transportation vehicles, agriculture technology and even military technology. Diesel engines are quite simple, very patient and durable. The debate over the diesel engines can bring benefits. Most likely, it will open ways to invest in research of diesel combustion processes, and may even improve rpm characteristics.

We are optimists that diesel engines will not go away. In this section, we will present the various variants of Common Rail Direct Injection CRDI systems used by different car companies. For details see Table 2.3 and in Refs. [2.14, 2.69-2.71].

Table 2.3. Common rail direct fuel injection systems used various companies for cars with diesel engines.

Car company References	Direct injection Diesel	Comments, particular elements
Audi [2.71, 2.72]	TDI	Turbocharged Direct Injection or TDI engines with common rail and piezo injectors
BMW [2.73, 2.74]	d, sd	Common Rail injection system, solenoid-valve injectors Sports edition, faster, two turbochargers
Ford [2.75, 2.76]	TDCi	Turbo Diesel Common rail injection, piezo or solenoid injectors
Honda, Acura [2.77, 2.78]	i-CTD, i-DTEC	Intelligent Common rail Turbocharged Direct injection, Bosch solenoid injectors Intelligent Diesel Technology Electronic Control, no variable valve timing, Bosch piezo injectors
Hyundai, Kia [2.79, 2.80]	CRDi,	Common Rail Direct Injection, Solenoid
Mazda [2.76, 2.81, 2.82]	MZR-CD, Skyactiv-D	MaZda Responsive cast-iron block and aluminium head. Common rail direct injection, solenoid injectors Multi-hole piezo injectors, two-stage turbocharger
Mercedes [2.83 - 2.85]	d, CDI	Controlled diesel injection (CDI) Common rail direct injection, piezo injectors
Mitsubishi [2.86]	Di-D, Di-DC	Direct injection diesel (Di-D) Turbocharged (T/C), intercooled (I/C) Direct injection diesel for club cab or double cab (Triton, also, Pajero), for harder work Common rail, solenoid or piezo injectors, MIVEC (not for all)
Nissan [2.87, 2.88]	dCi	diesel Common rail injection, solenoid or piezoelectric type injectors
Subaru [2.90, 2.91]	d, TD	Diesel or turbo diesel, common rail fuel system with solenoid injectors
Toyota [2.93, 2.94]	D-4D	Toyota common rail direct injection technology, solenoid type injectors
Volkswagen [2.71, 2.72]	TDI	Turbocharged direct injection, common rail, injectors types piezo

2.5 Overview of Common rail direct fuel injection systems in diesel engines

In the common rail system, fuel is distributed to the injectors from a high-pressure line, called the rail. The rail is supplied by a high-pressure fuel pump. Computer signal activates the injector for each cylinder. The system controlling both the injection timing and injection rate. Below presented are short overview of common rail direct fuel injection systems in diesel engines used by different car companies.

2.5.1 Audi TDI

Turbocharged Direct Injection or TDI engines with common rail and piezo injectors achieve extremely smooth and efficient combustion with excellent acoustic comfort. Particulate filter reduces emissions, which is fitted as standard. The turbocharger with variable turbine vane geometry plays a serious role in producing the engine's high torque and increasing the amount of power.

Control of the flow of air into the cylinder also achieves significant improvements in power build-up. This has the added advantage of allowing exhaust gas recirculation, which further reduces nitrogen oxide emissions [2.71, 2.72].

2.5.2 BMW d, sd

BMW was the first manufacturer which applied two-stage turbocharging to an automotive diesel engine. The two-stage turbocharger consists of two turbochargers of different sizes. It consists of two exhaust gas turbochargers of different sizes (high-pressure and low-pressure stages) connected in series, one after the other. A Common Rail injection system is used with solenoid-valve injectors. The latest versions of BMW diesel engines use Bosch third-generation piezo 1600 atm common rail fuel injection systems [2.73, 2.74].

2.5.3 Ford TDCi

The Ford diesel engine was released as the Ford Duratorq TDCi with Delphi second-generation common rail technology.

To meet Euro 4 emissions standards, the 1.8-liter engine was equipped with the Siemens (Continental) 1600 atm piezo common rail fuel system in conjunction with an enhanced EGR (exhaust gas recirculation) system and adapted turbocharger for this system.

Also, for fuel injection are used Denso solenoid common rail system [2.75, 2.76].

2.5.4 Honda, Acura i-CTD, i-DTEC

Honda starts diesel engine design in 2005. The N series common-rail diesel engines were used for medium-sized Honda vehicles. Honda named their engines as i-CTD (Intelligent Common Rail Turbo charged Direct injection). The most notable feature is the aluminium block. The valvetrain is a DOHC style with chain-driven camshafts. The fuel system is a high-pressure

(1600 atm) common rail direct injection type with a variable geometry turbocharger with intercooler.

The i-DTEC engine uses a 2-stage turbo charger from Wastegate Type & Variable Geometry Turbocharger (VGT). Also, in engine system included diesel particulate filter (DPF), idle stop system, exhaust gas recirculation system (EGR) and small size intercooler.

For i-CTD Bosch uses 2nd generation 1600 atm solenoid but for i-DTEC uses Bosch 3rd generation 1800 atm piezo injectors [2.77, 2.78].

2.5.5 Hyundai, Kia CRDi

CRDi stands for Common Rail Direct Injection, meaning direct injection of the fuel into the cylinders of a diesel engine via a single, common line, called the common rail which is connected to all the fuel injectors. Bosch common rail electronic diesel control (EDC) - Electronic controlled and high precision Injectors are used and installed in the centre of the combustion chamber. Injection pressure reaches up to 1350 atm and fuel injectors are solenoid valves [2.79, 2.80].

2.5.6 Mazda MZR-CD, Skyactiv-D

The diesel MZR-CD engines use a cast-iron block (virtually identical to the Mazda F engine) and an aluminium cylinder head. Diesels cleaner and more powerful common rail direct injection turbocharged version of Mazda engines was started with 2005. Denso (solenoid injectors) 1800 atm second generation common rail system that, depending on driving conditions, uses multi-stage injection of up to nine times per cycle with six-hole injectors [2.15, 2.76].

In 2011, Mazda replaced the MZR with their new SkyActiv generation engine it. SkyActiv-D is a family of turbocharged diesel engines, designed to comply with global emissions regulations [2.81, 2.82]. The cylinder compression ratio was reduced to 14.0:1. Programmable multi-hole piezo injectors help to start cold engine. Engine misfiring is prevented via variable valve lift at exhaust. The SkyActiv-D also uses a two-stage turbocharger, in which one small and one large turbo are selectively operated, according to driving conditions. Features of Skyactiv-D is fuel economy 20% better thanks to the low compression ratio of 14.0: 1 and other innovations. A new two-stage turbocharger realizes smooth and linear response from low to high engine speeds. Increase torque at low and high rpm ends. The engine may achieve up to the 5200-rpm limit.

2.5.7 Mercedes d, CDI

In 2007 were the ten-year anniversary of the market launch of the Mercedes controlled diesel injection (CDI), clean burning diesel technology. Before 1997 Merced diesel technology was different.

In 2007 piezo injectors on diesel engines formed part of the new technologies. In 2009, Mercedes-Benz introduced the fourth generation of its tried-and-trusted common-rail direct-injection system into series production. The maximum rail pressure stands at 2000 atm. Newly developed piezo injectors use piezo-ceramic properties to change their crystal structure, and thickness in a duration of nanoseconds when electrical voltage is applied. The new engines run much smoother at idle than its predecessor [2.83 - 2.85].

2.5.8 Mitsubishi Di-D, Di-DC

Mitsubishi Motors Corporation (MMC) in 2010 year has developed a Euro 5-regulation 4N13 1.8L/4N14 2.2L passenger-car diesel engines in which a low compression ratio is combined with the Mitsubishi Innovative Valve timing Electronic Control system (MIVEC). By setting the compression ratio at the lowest of any passenger-car diesel engine (14.9:1), Mitsubishi achieved a superior combination of full-load performance, fuel economy, emissions performance, and combustion noise. To overcome the challenge of achieving stable cold start ability and unburned-hydrocarbon emissions, MMC used the MIVEC.

In debated diesel engines and also in 4N15 2.4L is used common rail with direct injection system (Di-D, Di-DC). In the diesel engines are used solenoid type or piezo injectors. The piezo injectors in common rail require higher fuel pressure up to 2000 atm [2.86].

2.5.9 Nissan dCi

The diesel engines K9K is a family of straight-4 turbocharged diesel engines co-developed by Nissan and Renault. Acronym dCi is a diesel common-rail injection. More new technologies also include a variable-pressure oil pump, and a low-pressure exhaust-gas recirculation system.

The diesel engines M9R and M9T are a family of straight-4 automobile diesel engines co-developed by Nissan and Renault, recently calling them the M engines. Features of the diesel engines include a cast-iron block, an aluminium alloy cylinder head with double overhead camshafts, and a 16-valve layout. For direct injection used common rail with Bosch or Denso piezoelectric or solenoid type injectors [2.76, 2.87, 2.88].

2.5.10 Subaru d, TD

Subaru is a young entrant in the diesel market and starts in 2007. Interesting that, Subaru has introduced the first flat (boxer) diesel (D) engine for passenger cars.

The boxer diesel engine has been developed to complement their range and fall in line with their vehicle weight distribution and all-wheel drive transmission strategies. It was launched in 2008 for the European market. Technically, apart from being horizontally opposed, the engine follows modern practice, with a bore and stroke of 86 mm, a compression ratio of 16.3:1, four-valve aluminium cylinder heads with central vertical injector. Denso 1800 atm common rail fuel system with solenoid injectors, a variable geometry turbocharger and a high flow EGR system with a cooler used too. Turbo diesel engine was claimed as diesel engine with turbocharger [2.89 -2.91]. However, life going and is doing corrections. It was announced that Subaru will end production of diesel engines likely to run out in mid-2019. Let's wait [2.92].

2.5.11 Toyota D-4D

Toyota D-4D actually stands for Direct Injection 4 Cylinder Common Rail Diesel Engine. Toyota upgraded their small diesel engines with a newly designed 1.4 L engine in 2004. This engine has an all-aluminium construction. It has a two-valve cylinder head and has a compression ratio of 18.5:1. A notable feature is an intake manifold integrated into the cylinder head. Otherwise, the engine features follow current practice, having a Bosch second-generation 1600 atm common rail fuel injection system and being turbocharged and intercooled to give a specific power of 40 kW/L.

The Toyota 1VD-FTV engine is the first V8 diesel engine produced by Toyota. It is a 32-Valve DOHC, with Common rail fuel injection and either one or two variable geometry. Direct injection system D-4D uses solenoid type injectors [2.93, 2.94].

Japanese car giant Toyota told reporters at the Geneva Motor Show that it would stop selling diesel cars in Europe. They will not develop new diesel technology for passenger cars and will continue to focus on hybrid vehicles [2.95].

2.5.12 Volkswagen TDI

Turbocharged direct injection or TDI is a design of turbodiesel engines featuring turbocharging and cylinder-direct fuel injection that was developed and produced by the Volkswagen Group.

Volkswagen introduced its well-known 1.9 L diesel engine with direct injection in 1992 and since then it has been produced in a number of forms with an increase in performance at each stage. The first stage was in 1995 when a variable geometry turbocharger was added.

The newer 2.0 L in-line four-cylinder engine was upgraded at the end of 2007 with a new cylinder head featuring four valves per cylinder. Intake boost is supplied by a variable turbine geometry exhaust turbocharger. The Bosch CRS 3.2 common rail system delivers up to 1800 atm pressure and fuel is injected by Bosch CRI 3.2 injectors with eight holes. The engine equipped with rapid-action piezo injectors [2.71, 2.72, 2.96].

2.6 Engine fuel

The best fuel we have are hydrocarbons: Gasoline, diesel and ethanol **(**ethyl alcohol). We get those mostly from fossils right now, and we use them for everything. Part of fuel is ethanol, which mostly is biochemical/fermentation product. However, we may get about 20% of our energy from wastes converted into hydrocarbons, maybe more. This may solve two huge problems: excess CO_2 from fossil fuels, and mountains of wastes polluting the world [2.97].

The fuel density and an approximated specific heat energy for the few main fuel types are presented in Table 2.4 [2.98-2.100].

$$E[MJ/m3] = \rho[kg/m3] \times E[MJ/kg], \quad (2.1),$$

$$E[MJ/L] = \rho[kg/L] \times E[MJ/kg]. \quad (2.2).$$

Table 2.4. Fuel of motor vehicles density and energy efficiency. Fuel densities were reconstructed from energy data.

Fuel type/Energy source	Density ρ, kg/m^3	Density ρ, kg/L	Energy, MJ/L	Energy, MJ/kg
Gasoline (petrol)	740	0.74	34.8	47
Autogas, liquid petroleum gas (LPG), 60% propane & 40% butane	530	0.53	27	51
Ethanol	756	0.756	23.5	31.1
E85, 85% ethanol & 15% gasoline	764	0.764	25.2	33
Diesel	804	0.804	38.6	48
Biodiesel	880	0.88	35.1	39.9
Liquid natural gas	460	0.46	25.3	55
Liquid hydrogen	72	0.072	9.3	130
Electrical Li-ion battery Gravimetric energy density				0.44*
Gravimetric energy density definition see in [2.101]. * - Gravimetric energy density for Li-ion battery = 123Wh/kg×3600 = 0.44 MJ/kg [2.102].				

An octane rating, or octane number, is a standard measure of the performance of an engine or aviation fuel. The higher the octane number, the more compression the fuel can withstand before detonating (igniting). In broad terms, fuels with a higher-octane rating are used in high performance gasoline engines that require higher compression rates.

The octane quality of a gasoline is its ability to resist detonation, a form of abnormal combustion. Detonation occurs when the air-fuel mixture reaches a temperature and/or pressure at which it can no longer keep from self-igniting. Octane numbers can be very confusing due to several different terminologies.

The most common type of octane rating worldwide is the Research Octane Number (RON). RON is determined by running the fuel in a test engine with a variable compression ratio under controlled conditions. Research Octane Number determined in a single cylinder variable compression ratio engine. A good quality racing gasoline has a RON in the range of 110 to 115. The difference in the spread of RON is not very important to racing engines.

There is another type of octane rating, called Motor Octane Number, which is a better measure of how the fuel behaves when under load. MON testing uses a similar test engine to that used in RON testing, but with a preheated fuel mixture, a higher engine speed, and variable ignition timing to further stress the fuel's knock resistance. This is a very important number for racing engines since they spend a high percentage of their lives under high speed and high load conditions. Racing engines cannot afford to be short on octane quality, since detonation or preignition will quickly reduce a racing engine to junk.

(R+M)/2 is the average of RON (R) and MON (M). It is sometimes referred to as the anti-knock index (AKI). As a rule, this number must be posted on the dispensing pump at retail outlets in most states. It is the most commonly used octane reference today. It was developed as a compromise between RON and MON for advertising purposes and also to keep from confusing the consumer with too many different terms. It has erroneously been referred to as road octane number [2.103, 2.104].

For diesel engines is important cetane number (CN). It is an indicator of the combustion speed of diesel fuel and compression needed for ignition. It plays a similar role for diesel as octane rating does for gasoline. The higher the number, the better the fuel burns within the engine of vehicle. Diesel engines operate well with a CN from 48 to 50. Fuels with lower cetane number have longer ignition delays, requiring more time for the fuel combustion process to be completed. Hence, higher speed diesel engines operate more effectively with higher cetane number fuels [2.105]. High-speed, modern diesel engines, especially vehicle engines, need cetane numbers above 52. In Table 2.5 presented octane ratings for various selected fuels [2.106, 2.107].

Table 2.5. The lists octane ratings for some selected fuels.

Fuel	RON	MON	AKI=(RON+MON)/2
Diesel	15-25		
Euro Super, Regular unleaded	95	85-86	90-91
Super Plus, Germany	98	88	93
Ethanol	108.6	89.7	99.15
Propane	112	97	105
Methane	120	120	120
Hydrogen	>130		

Three standards covered automotive fuel quality: EN 228 for gasoline (petrol) [2.108], EN 590 for diesel [2.109] and EN 589 for automotive LPG.

The EN 228 European Standard specifies requirements and test methods for marketed and delivered unleaded petrol. It is applicable to unleaded petrol for use in petrol engine vehicles designed to run on unleaded petrol.

The EN 590 European Standard specifies requirements and test methods for marketed and delivered automotive diesel fuel. It is applicable to automotive diesel fuel for use in diesel engine vehicles designed to run on automotive diesel fuel.

Note: There are two types of diesel fuel: 1-D (# 1) - kerosene, also known as winter diesel, and 2-D (# 2) - most used. Paraffin in diesel fuel begins to stiffen below about -6 ^{0}C. In fuel (# 1) is lower paraffin wax concentration, it means lower freezing temperature up to -40 ^{0}C. In winter is used mixture of fuels (# 1) and (# 2). For more information see document [2.109].

It is important for the consumer to choose the right fuel for the car. It is best to follow the instructions of the car manufacturer. Below in Table 2.6 presented example of fuel instructions for the Mitsubishi ASX [2.110].

Table 2.6. Example of fuel instructions for the vehicle Mitsubishi ASX (2018).

Petrol-powered vehicles	Diesel-powered vehicles
Unleaded petrol octane number (EN228) For 1600 models 95 RON or higher	Cetane number (EN590) 51 or higher
CAUTION	CAUTION
For petrol-powered vehicles, the use of leaded fuel can result in serious damage to the engine and catalytic converter. Do not use leaded fuel	Diesel-powered vehicles are designed to use only diesel fuel that meets the EN 590 standard. Use of any other type of diesel fuel (bio diesel, methyl ester, etc.) would adversely affect the engine's performance and durability
Petrol	Diesel
Identifier for petrol-type fuels	Identifier for diesel-type fuels
	
E5: Petrol fuel containing up to 5.0 % (V/V) ethanol	B7: Diesel fuel containing up to 7.0 % (V/V) Fatty Acid Methyl Esters - (EN 590 standard) compliant diesel
E10: Petrol fuel containing up to 10.0 % (V/V) ethanol	Above -5 °C: Summer diesel Below -5 °C: Winter diesel
The petrol engines are compatible with E5 type petrol (containing 5 % ethanol) and E10 type petrol (containing 10 % ethanol) conforming to European standards EN 228	The diesel engines are compatible with B7 type diesel (containing 7 % fatty acid methyl esters) conforming to European standards EN 590
CAUTION	CAUTION
Do not use more than 10 % concentration of ethanol (grain alcohol) by volume. Use of more than 10 % concentration may lead to damage to your vehicle fuel system, engine, engine sensors and exhaust system	Do not use more than 7 % concentration of fatty acid methyl esters (bio diesel) by volume. Use of more than 7 % concentration would adversely affect the engine's performance and durability
Note: % (V/V) is used to represent the volume fraction.	

Ethanol contains about one-third less energy than gasoline. So, vehicles will typically go 3% to 4% fewer km per litre on the E10 than on the 100% petrol.

2.7 Energy losses in a vehicle

Fuel economy is one of the most actual problem [2.111, 2.112]. Only about 12-30% of the energy from the fuel you put in your tank gets used to move your car on the road or run useful accessories, such as air fan or radio. The rest of the energy is lost firstly in conversion from heat energy to mechanical energy, secondly lost in engine and driveline inefficiencies and for idling. Therefore, the potential to improve fuel efficiency with advanced technologies is enormous.

Electrical vehicles convert about 59-62% of the electrical energy from the grid to power at the wheels. It must be borne in mind that electricity must first be produced. The cost of electricity generation is also high, with only about 40-60% of energy from conventional sources being converted into electricity. Adding all the losses from electricity generation, transmission to conversion into car mechanical energy, we get the same efficiency as using fuel directly in the engine. A simple obvious example. After all, in winter to heat a house with gas is significantly cheaper than using electricity. After all, we create heat just in the house, and otherwise we lose about half of our energy by producing electricity from gas in a power plant.

Advanced engine technologies such as variable valve timing and lift, turbocharging, direct fuel injection, and cylinder deactivation can be used to reduce these losses. Also Stop/Start system and other innovation systems contributes to reducing fuel economy and gas emissions.

There exist various loses of energy in some situations. In urban driving, significant energy is lost to idling at stop lights or in traffic. New technologies such as integrated starter/generator systems help reduce these losses by automatically turning the engine off when the vehicle comes to a stop and restarting it instantaneously when the accelerator is pressed.

Air conditioning, power steering, windshield wipers, and other accessories use energy generated from the engine. Energy is lost in the transmission and other parts of the driveline.

Aerodynamic losses are also important to the car. In a few sentences we may remind the physics. At low speeds there is laminar flow, air resistance is proportional to the speed of the car. At high speed, turbulence generation begins, and the resistance force is proportional to the square of the flow velocity. It begins at about 100 km/h. If you increase speed 30 km/h you approximately add fuel consumption of about 1-2 L/100 km (it depends on the car and driving conditions). Drag is directly related to the vehicle's shape. Smoother vehicle shapes have already reduced drag significantly, but further reductions of 20-30 percent are possible (prognosis). Our experience shows that the vehicle minimal fuel consumption is when car of an average speed is of around 80 km/h and for a dry road and ideal weather conditions. It then coincides with the fuel consumption data for the car presented in the manufacturer car specifications.

Rolling resistance is a measure of the force necessary to move the tire forward and is directly proportional to the weight of the load supported by the tire. In addition, any time you use your brakes, energy initially used to overcome inertia is lost.

One interesting observation. Take a look at the car's display average speed. You will see that it is about 30 km/h in the city and about 75 km/h on the roads. In the trip you have to stop for refuelling or just rest. You may conclude: your extremely fast driving is completely meaningless. You consume a lot of fuel, you increase your travel costs, you not save nature, and most **importantly it increases the serious consequences at an accident.**

The Table 2.7 presents energy distribution in gasoline (petrol) vehicles. Understanding the power consumption of the car, you can plan more efficient voyages, which contributes to reducing fuel economy and gas emissions [2.113]. For other hybrid and electrical vehicles please find in Refs. [2.114, 2.115].

Table 2.7. Energy distribution in gasoline vehicles. Data presented in percentages %.

Energy distribution in gasoline car	Combined, City/Highway	City, with Stop & Go	Highway
Engine Losses:	68-72	71-75	64-69
thermal (radiator, exhaust)	58-62	60-64	56-60
combustion	3	3	3
pumping	4	5	3
friction	3	3	3
Auxiliary electrical losses (climate control, headlights, comfort)	0-2	0-2	0-2
Engine service losses (pumps, ignition, electronic control)	4-6	5-7	3-4
Power to wheels:	16-25	12-20	20-30
wind resistance	8-12	3-5	12-19
rolling resistance	4-7	3-5	5-9
breaking	4-7	6-10	2-3
Drivetrain losses	5-6	4-5	4-7
Idle losses (when the vehicle is not in motion)	3	6	0
Example, Fuel consumption* in L/100 km	5.7 L/100 km	7.0 L/100 km	5.0 L/100 km
* - Mitsubishi ASX 2018 (petrol, with AS & G) [2.110].			

2.8 Automatic Stop-Start system

When in the car is installed the Auto Stop-Start function, significant reductions in fuel consumption and CO_2 emissions are achieved [2.116]. That is most important within the town driving.

Stop-Start system typically found in hybrid vehicles that automatically stops and restarts the internal combustion engine to reduce the quantity of your time the engine spends idling. It improves fuel economy. The electrical power consumption is low too. When stops engine idling system, electric power steering or other unnecessary consumption systems are switched off. The system works with other energy saving systems. For instance, the alternator is charging the battery only when the car is braking, moves from inertia and decelerating. Also, more technical information about Stop-Start system see in Chapter 4.

All these systems work similarly and are ubiquitous in hybrid cars. When the car involves a stop, the engine computer cuts spark and fuel. When the driver lifts his foot off the brake, or engages the clutch, the engine fires back up.

On a manual transmission vehicle, Stop-Start is activated as follows: Stop car and press clutch, move gearshift to neutral, release clutch, then the engine stops. The engine won't stop if the car is moving, albeit the aforementioned steps are followed. The engine restarts when the clutch is pressed before selecting a gear to manoeuvre the car. The principle of the Stop and Start system is that it is adaptive system. This suggests that in certain circumstances the engine won't stop and in other circumstances the engine will restart by itself. That conditions are listed, for instance, for Mitsubishi ASX [2.110], in Table 2.8. To get full picture about Stop-Start system in your car, please read manual.

Table 2.8. Conditions, when vehicle with Stop and Start system will restart by itself and the engine will not stop. It is listed for Mitsubishi ASX.

Engine will restart by itself	The engine will not stop
The interior temperature rises and the air conditioning starts operating in order to lower the temperature	Ambient temperature is lower than approximately 3 °C
Electric power consumption is high	After the engine restarts automatically and the vehicle stops again within 10 seconds
The brake pedal is depressed repeatedly	After the engine restarts automatically and the vehicle remains stationary
Vehicle speed is 3 km/h or higher when coasting on a slope	Brake booster vacuum pressure is low
When the air conditioning is operated by pressing the air conditioning switch	Engine coolant temperature is low
When the preset temperature of the air conditioning is changed significantly	Air conditioning is operating and passenger compartment has not sufficiently cooled
When the air conditioning is operated in AUTO mode where the temperature control dial is set to the max. hot or the max. cool position (with automatic air conditioning)	When the air conditioning is operated in AUTO mode where the temperature control dial is set to the max. hot or the max. cool position (with automatic air conditioning)
Notes: If Stop-Start button switched off. After restarting engine manually, the Stop-Start system automatically returns to initial position and you may repeatedly switch off if want. Cruise control does not change operation position after restarting engine automatically or manually.	

Automatic Stop-Start system may access fuel economy few percentages. It depends for the variability of driving conditions out there. People that briefly stops have benefit less than those that sit without idling at a lot long traffic light signals for various directions. The longer you sit in one place, the more you save fuel [2.117].

Exist natural question, the Stop-Start system doesn't damage the car engine. For Stop-Start system the fast start system is required. The system after stop leaves a ready-made fuel system and the engine remains warm because it stops for a brief time. It's unlikely that an improved starter possible discharge a larger capacity battery. If a standard car starts up to 50 000 times, the amount of stop-start can reach 500 000 times in exploitation years. If the Stop-Start system is installed in your car, but you are doing not use it, however in your car is installed better long-life battery and an improved starter. In Table 2.9 presented some selected vehicles Stop-Start, Idle-Stop or other names systems.

Table 2.9. Vehicle Stop-Start or Stop and Go systems.

Car company	Stop-Start system,	Comments, particular elements
Audi [2.118, 2.119]	Start-Stop	Start-Stop System
BMW [2.120, 2.121]	Stop and Start (MSA)	Motor-Start-Stopp-Automatik (MSA). It is included in Efficient Dynamics system
Ford [2.122]	Start-Stop	DENSO's stop/start technology
Honda, Acura [2.123]	Idle-Stop	Idle start/stop system (also stops lights)
Hyundai, Kia [2.124, 2.125]	ISG	Idle Stop & Go (Intelligent Stop & Go)
Mazda [2.126, 2.127]	i-Stop	Idling Stop, uses smart start system
Mercedes [2.128, 2.129]	ECO Start/Stop	ECO Start/Stop function is part of BLUEFICIENCY system
Mitsubishi [2.110, 2.130]	Auto Stop & Go (AS & G)	Auto Stop & Go is part of more common fuel consumption system
Nissan [2.131]	Idling Stop	Automatically stops the engine when the vehicle is brought to a stop and activates as the car sets
Subaru [2.132]	Stop/Start	Auto Stop/Start system
Toyota [2.133]	Stop & Start	Stop & Start system
Volkswagen [2.134]	Start/Stop	Start/Stop is part of Blue Motion higher fuel efficiency system
Note: Because more and more cars are used keyless engine start systems, in the car exist Start/Stop button to start and stop engine and we get thus confusing in the terminology. For example, using the Auto Stop & Go or Idle (Idling) Stop names, this disadvantage is removed.		

Very interesting example is operation system of Mazda smart idling technology. It is installed in its gasoline engines, see in Fig. 2.13. Mazda's i-stop restarts the engine through combustion process. Fuel is directly injected into the cylinder while the engine is stopped and ignited to get downward piston force. Mazda's i-stop provides precise control over piston positions during engine shutdown. All the pistons stopped at the optimum positions. The control system identifies the initial cylinder for fuel injection system. It injects fuel and ignites and the engine restarts.

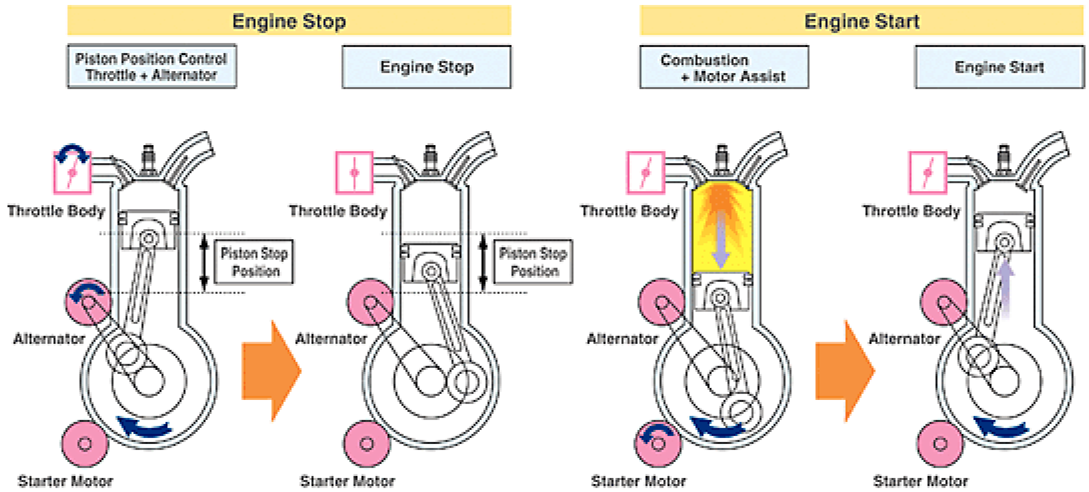

Fig. 2.13. Mazda i-stop with gasoline engines smart operating system model, Adapted from [2.127].

Mazda in diesel engines also uses smart i-stop technology. To start the diesel engine, it is necessary to compress the air-fuel mixture until it ignites itself. For this purpose, sufficient air compression has got to be in a diesel engine. Most diesel engine stop-start systems require two engine cycles to restart. The Mazda i-stop uses only one cycle. This is often made possible by the precise piston positions when the engine stops. It leads to the fastest diesel engine restarts within the world. Restart time of approximately 0.40 seconds. The restarting process is smooth and no vibration or noise.

There in worldwide exist emission standards are the legal requirements governing air pollutants released into the atmosphere. The European Union also has its own set of emissions standards that all vehicles must meet, see, for instance, Regulation (EC) No 443/2009. Foremost important are CO_2 emissions, also toxic emissions as CO, NO_x and other (for more see Euro 6 standard). CO_2 emissions reflects fuel consumptions; more fuel, more emissions.

Currently, legal CO_2 emissions for passenger cars ((EC) No 443/2009) are 130 g/km, which means that fuel consumption is about 5.6 L/100 km of petrol or 4.9 L/100 km of diesel.

From 2021 the EU average CO_2 emissions from new cars will have to be below 95 g/km. This emission corresponds to a fuel consumption of approximately 4.1 L/100 km for petrol or 3.6 L/100 km for diesel. The testing procedures for new cars are also changing.

We need to reduce CO_2 emissions and fuel consumption. The Stop-Start system does this. Please use it in your car and do not switch off without important reason.

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Chapter 3 Driving & braking

One of the most important system in the car after engine is drivetrain. The drivetrain of a motor vehicle is the group of components that deliver power to the driving wheels [3.1]. This excludes the engine or motor that generates the power. Mostly common term of car is powertrain, for example, see Fig. 3.1. A vehicle's powertrain in simple words is the go parts.

Powertrain includes the engine, transmission, and drivetrain. It contains components that transfer engine power to the wheels and the road. As a result, the vehicle is moving. It's a big system with a lot of moving parts. If any part of the powertrain fails, surely you do not get where you need to go. In this chapter we do not discuss the traditional components of the vehicle powertrain. How it works it is possible to found in textbooks or specialized engineering books, for instance, see in Refs. [0.7, 0.10, 0.13, 0.14, 0.35]. We will consider only part of the car elements and systems related to fuel consumption, driving safety and also elements which was mostly influenced by high technology innovations.

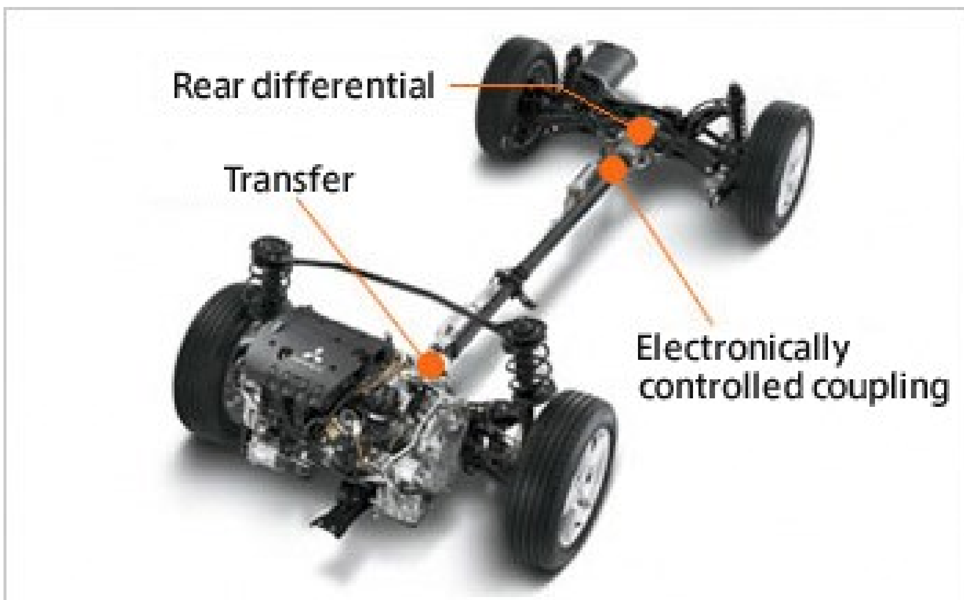


Fig. 3.1. Mitsubishi vehicle powertrain with the electronically controlled 4WD system. Adapted from [3.2].

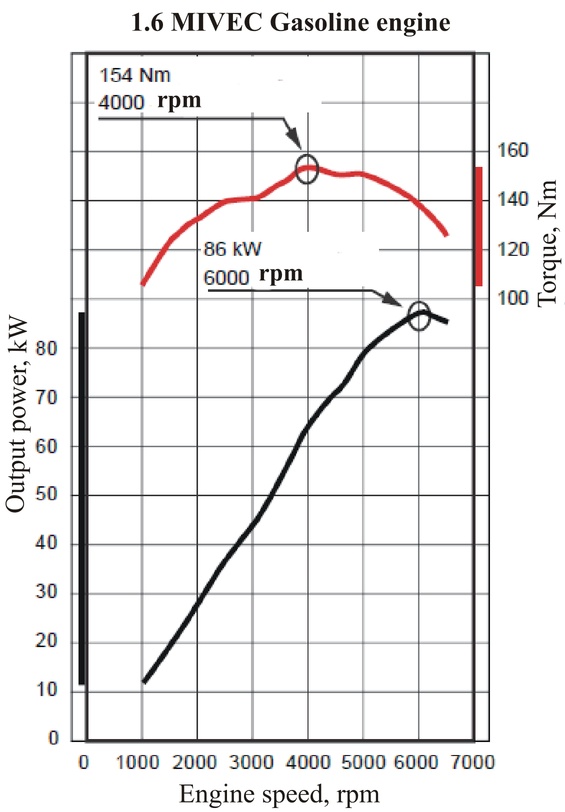
3.1 Gear box (transmission)

The gearbox (transmission) is the second stage in the transmission system, after the clutch. It is usually bolted to the rear compartment of the engine, with the clutch between them.

Modern cars are equipped with a manual transmission (MT), an automatic transmission (AT) or with a continuously variable transmission (CVT) [0.25, 0.35].

The internal combustion engine's power is linearly depended on rotation speed of crankshaft and the torque is close to the constant value for only a certain rotation interval from 1000 rpm to 4000 rpm (diesel) or to 6000 rpm (petrol), for example, see Fig. 3.2. Note: rpm stands for revolutions per minute, and it's used as a measure of how fast any machine is operating at a given time. In cars, rpm measures how many times the engine crankshaft makes one full rotation every minute, and along with it, how many times each piston goes up and down in its cylinder. Power is presented not only in kilowatts, but also in horsepower (hp) units. 1 kW = 1.34 hp or 1hp = 0.746 kW. For horsepower unit's designation also is used other, e.g., unit PS. It comes from a German word Pferdestärke, which meaning Horsepower. These two units differs a little, 1 PS = 0.986 hp.

We need to change the car's speed in a very wide interval. For example, engine rotation changes from 1000 rpm to 5000 rpm (5 times), however a car have to be accelerated from 1 km/h to 100 km/h (100 times). It is not enough to do this using only the accelerator pedal. In addition, a gear box is used. In a modern car, the gear shift lever is almost always mounted vertically on the centre console and connected to the transmission via a linkage.



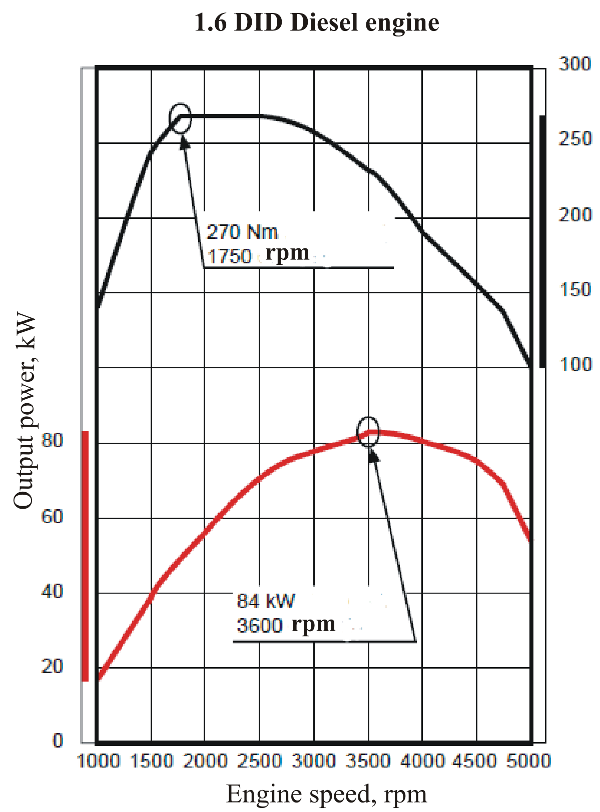


Fig. 3.2. Relation between engine rotation speed and power output for Mitsubishi gasoline (left) and diesel (right) engines. Adapted from [3.3].

The transmission gearbox is employed to supply the gear reduction needed to transform the high speed of the engine to the required speed to drive the wheels. The gear box is the chief component of the transmission. The gearboxes within the front and rear wheel drive units are different.

It is usually used four, five (at present more common used), six, or more forward and one reverse gears within the gearbox. When the driver presses the clutch down, the sliding gear gets engaged with the acceptable gear. There are higher and lower gears which when engaged with the sliding gear provide high and low speeds, respectively. Modern manual gearboxes employ a diagonal gear that keeps the sliding gear synchronized with the most gears. This design prevents the gears from clashing with each other. Not all love manual transmission, but they lose a number of the pleasure of driving [3.4].

3.1.1 Automated manual transmission (AMT)

An automated manual transmission (AMT) [3.5] is basically a manual transmission. To convert a manual transmission into an automated manual transmission, the clutch pedal and the gear shift lever are replaced by electronically controlled actuators. If you're shopping for a car and you see the term automated manual transmission or sometimes automated-clutch manual transmission, it refers to a transmission that's mechanically similar to a stick-shift, except a computer performs the clutch work. According Table 3.1 different manufacturers use different names for AMT.

Table 3.1. Versions of automated manual transmissions.

Automated manual transmission (AMT)		
DCT	DSG	PDK
A dual-clutch transmission, BMW [3.6, 3.7]	A direct-shift gearbox (German Direkt), Volkswagen, Audi (S tronic) [3.8, 3.9]	Porsche double-clutch transmission, German Doppelkupplungsgetriebe [3.10 - 3.12]
The clutches operate independently. One clutch controls the odd gears, the other controls the even gears	In simple terms: two separate manual gearboxes and clutches contained within one housing and working as one unit	Porsche transmission is two gearboxes in one. It features hydraulically actuated wet-clutch packs
Boosts performance and provides the ultimate driving experience. Auto-switching and manual switching	Car accelerates faster than a manual-equipped model, and the gears shift almost immediately, leaving very little lag while accelerating	7-speed PDK, featuring both a manual and an automatic mode, is available as an option and offers extremely fast gear changes with no interruption in the flow of power

Automatic Manual Transmission often are named as Tiptronic-type transmission [3.13].

A Tiptronic transmission is an automatic transmission that includes an option to switch out of automatic mode and upshift or downshift by using paddles behind the steering wheel or by using the gear lever itself. The name Tiptronic is a registered trademark that is owned by car manufacturer Porsche. These are commonly known as dual-clutch transmissions.

A Tiptronic systems allow drivers to choose whether they want to drive automatic, where the computer does gear shifting or manual mode where the driver has the opportunity to change the gear. Other systems have tried to emulate the feel of manual without giving you full control.

A dual-clutch transmission (DCT) (sometimes referred to as a twin-clutch transmission or double-clutch transmission) is a type of automatic transmission or automated automotive transmission. A DCT is an automated manual transmission which uses two separate clutches, one of each odd and even gear sets. So, it almost seems like a DCT is two manual gearboxes stuffed into one housing. These DCTs are normally operated much like a standard automatic transmission, with a simple PRNDL (Park, Reverse, Neutral, Drive and Low) gear selector and no clutch pedal. They can also work just like an automatic transmission, shifting gears on their own, or can be manually controlled, via paddle shifters or a separate gate on the gear selector.

The advantages of a DCT are shift times, fuel economy and ease of operation. Modern day DCTs, like Porsche's PDK (Porsche Doppelkupplung) or BMW's DCT, can successfully upshift in around 60 milliseconds consistently.

Volkswagen designed (2002) a direct-shift gearbox (DSG) is an electronically controlled dual-clutch multiple-shaft gearbox in a transaxle design fully automatic or with semi-manual gear selection [3.14]. One outstanding design characteristic of the transversally mounted gearbox was a pair of wet clutches with hydraulically controlled pressure.

For enthusiasts, neglecting efforts the manual control and rapid shift times of a DCT, the manual gearbox is still the more fun and now engaging to drive.

3.1.2 Automatic transmission (AT)

Automatic transmission (AT) uses an automatic gearbox that allows the transmission to select the right gear, without having the driver to choose [0.26, 3.15, 3.16].
The traditionally most popular in automobiles is the hydraulic planetary automatic transmission.

This system uses a fluid coupling (torque converter) in place of a friction clutch. Gear changes hydraulically. In AT is used locking and unlocking a system of planetary gears. A hydraulic system monitors the pressure of fluids in the engine and engages the appropriate gear with the help of a torque converter, with respect to the engine fluid's pressure. The AT in principle is a simple system.

The system includes torque converter, fluid pump, planetary gear sets, clutches, bands and a computer-controlled hydraulic valve body to transmit torque and to change gear ratios, see Table 3.2 and Fig.3.3.

Table 3.2. Automatic transmission layout parts.

Parts	Components	Operation
Torque converter (1)	Impeller (as pump) Stator (fluid distributor) Turbine (rotate transmission) Lock-up clutch (included on modern, works ≥ 60 km/h)	It takes the place of a clutch in a manual transmission
Planetary gear sets (2 or more)	Central sun gear (sun wheel) Ring gear (larger concentric gear with internal teeth) Planetary carrier Planetary pinions (3)	Changing gear ratios Reverse moving (planet gears will act like the idler gear in a manual transmission) Overdrive allows rotating speed higher than engine
Pump (1)	Mostly gear pump	Generates fluid pressure It initiates transmission fluid to move through the valve body, which in turn controls the clutches and bands that control the planetary gear sets. It feeds the torque converter
Clutches, more correctly Clutch packs (4 or other number)	Drum Friction disks Separator plates Pressure plate (Clutch hub)	No fluid pressure applied to the clutch pack; the clutches are allowed to turn without the application of that gear
Bands	The bands steel bands that wrap around sections of the gear train and connect to the housing	The band brings the drum to a stop and holds it there. They are actuated by hydraulic servo
Valve body	Main control centre (electronic and hydraulic)	It allows the flow of hydraulic fluid to different valves to direct the right clutch and switch the gear appropriately according to the driving situation
Sensors	Speed Pressure Temperature Transmission position	Sensors, read parameters
Actuators	Transmission solenoid (open, close fluid flow) Hydraulic Servo (cylinder, piston, spring) moves piston, spring return	The fluid pressurizes transmission's clutches and bands and allows to change gears. Uses Servo

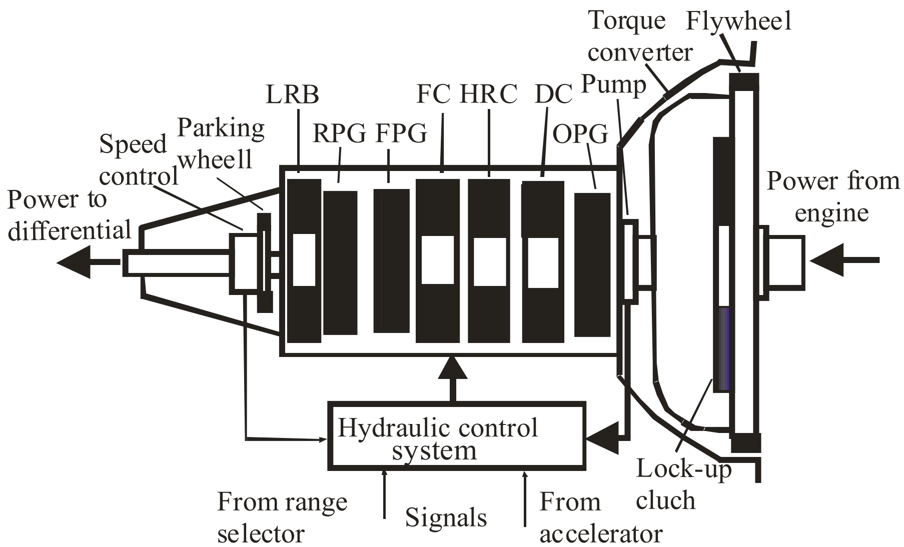


Fig. 3.3. Automatic transmission block diagram. Clutches (Clutch packs): DC is drive clutch, HRC is High and reverse multiplate clutch, FC is Forward clutch, LRB is Low and reverse multiplate brake. Planetary gear sets: OPG is overdrive planetary gear set, FPG is forward planetary gear set, RPG is reverse planetary gear set.

The most important elements in automatic transmission system are Torque Converter and Planetary gears, see Fig. 3.4. To understand how torque converter works, please do a simple experiment at home. Take two fans in front of each other. Plug in one and start blowing air. The front fan will also start rotating. In the torque converter flows pressurized fluid and the mechanism of operation is more complex. It consists of impeller, turbine and other elements. The fluid that is used in a torque converter is a hydraulic fluid or more specifically, torque fluid. The transmission of the Torque from the engine to the gearbox and further to the wheels is soft.

Multiple disk clutches are used for planetary gears control. Clutches drive pressurized fluid. Solenoid type valves control pressure of liquid. Finally, it is obtained that the AT speed is controlled by electrical signals sent from a computer (electronic control unit).

The torque converter in an automatic transmission performs the same function as the clutch in a manual transmission. Torque converter connects gearbox to engine and disconnects gearbox from engine. The engine also needs to be connected to the rear or front wheels. The vehicle will move and with a disconnected engine. The engine can continue to run when the vehicle is stopped too. In cars with AT a new parking problem (hand brake) arises. To solve this problem in an automatic transmission there used parking pawl. It stops rotate the ring (wheel) with teeth on the output shaft of AT.

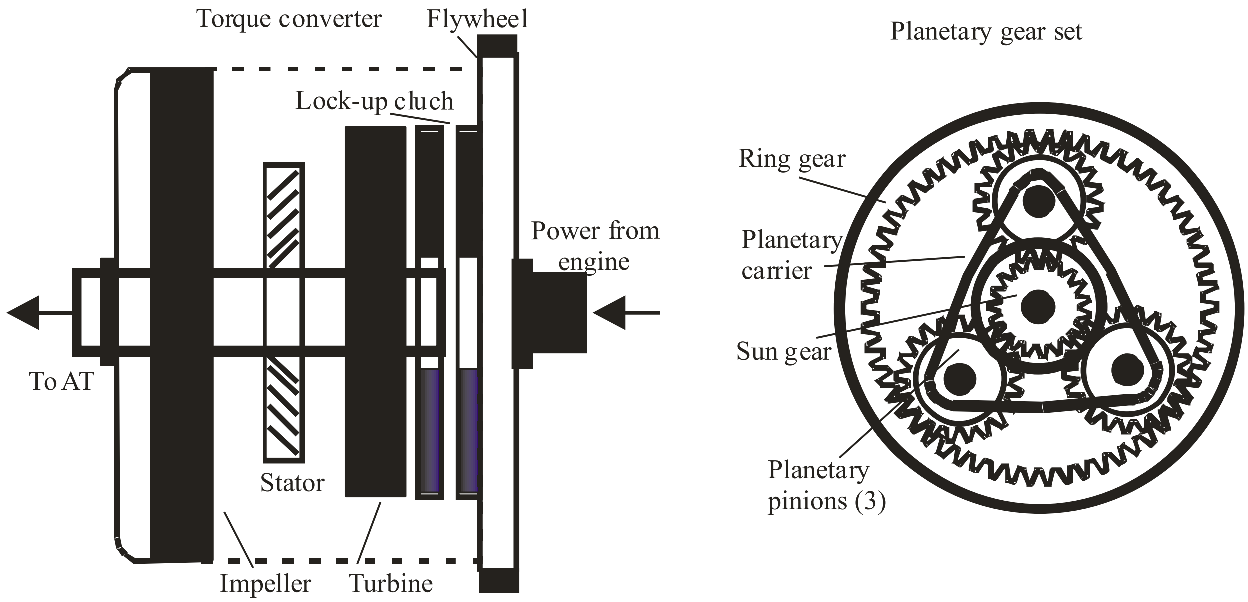


Fig. 3.4. Torque converter block diagram (left) and Planetary gear set (right). Clutch means clutch packs.

Reverse gear in AT, for example, may be organized as follows. One planetary gear set can combine reverse drive and five levels of forward drive [3.15]. It all depends on which of the three components of the gear set is moving or held stationary. For instance, in automatic drive the reverse moving is very similar to first gear. When the transmission is put into reverse position, the small sun gear through planetary pinion turns the outer ring gear backwards. The planet carrier is held by the reverse band to the housing. It is similar operation as idler gear in manual transmission. The idler gear is what allows your car to travel in reverse.

The torque converter allows the engine to be idle geared with the vehicle stopped and to multiply the engine torque during the initial stages of acceleration. Once you release the brake and tread on the accelerator, the engine accelerates and pumps more fluid into the converter. The converter transmits more power and also the wheels will receive more torque. Car begins to accelerate.

Torque converters are not 100% efficient. Some energy is lost between the input (the impeller) and the output (the turbine) sections. The turbine speed is approximately 90% of the impeller speed. There is generally no direct connection between the pump and turbine aside from the fluid. The efficiency of conventional automatic transmissions ranges from 86 to 94 percent [2.32]. The problem of effectiveness was improved in other way. Additional lock up clutch is added within the automatic transmission. The lock-up clutch mechanism connects the engine power mechanically directly to the automatic transmission output shaft. When the vehicle reaches a certain speed, the lock-up clutch mechanism is employed and torque is transmitted directly to the output shaft. The clutch allows the automated transmission to realize higher efficiency. Four-speed automatic transmissions are used for a long time. However, six-, seven- or eight-speed automatics are common today, up to 10 speeds are used too. The automatic transmission fluid (ATF) is typically coloured red or green to make it different from motor oil and other fluids within the vehicle.

An automatic transmission uses sensors to determine when it should shift gears, and changes them using internal fluid pressure. As you push the throttle to speed up, the fluid moves the turbine faster to send more power through the transmission.

The torque converter also protects the engine, gearbox and other mechanisms from overload. It softens the car drive and makes the car more comfortable.

3.1.3 Front-wheel drive (FWD) manual transmission

The main elements of the power train in front-wheel drive car are transversely mounted. The engine and the transmission, which transfers the torque of the engine to the drive wheels through a short drive shaft, are also installed transversely. Front-wheel drive cars use the same transmission principles as rear-wheel-drive cars. The mechanical components may vary in design according to the engine and gearbox layout. The typical FWD transmission assembly is a very compact.

A transversely mounted engine and transmission assembly is the common arrangement for a front wheel drive vehicle. In front-wheel drive cars few functionality units can be combined in one and named as transaxle, see Fig. 3.5. A transaxle is a major automotive mechanical component that combines the functionality of the transmission, axle, and differential into one integrated assembly [0.7, 0.13]. A transaxle performs both the gear-changing function of a transmission and the power-splitting ability of an axle differential in one integrated unit [3.17, 3.18]. This compact transaxle configuration normally requires the gearbox input and output shaft to be at the same end, so a two-shaft layout is used.

Figure 3.5 shows the layout of a five-speed and reverse gearbox. In this design each shaft is supported by a ball race at the non-driving end. At the opposite end the radial load is much heavier, therefore a roller race is equipped. Two-shaft layout gives a more rigid gear assembly and a quieter gearbox result.

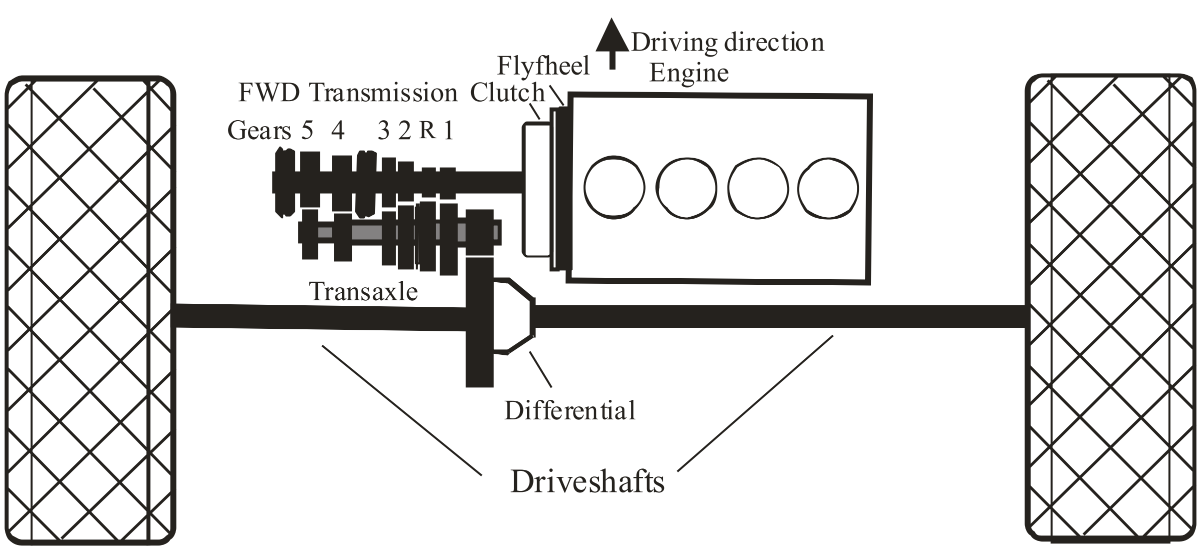


Fig. 3.5. Front-wheel drive manual transmission. Five-speed and reverse gearbox.

In manual transmission gearboxes the reverse idler gear is used for the reverse driving. This gear is used in the transmission to produce a reverse rotation of the transmission output shaft. The idler assembly is made of a short drive shaft and may be independently mounted in the transmission case [0.13]. All gears, including reverse, are synchromesh. A synchromesh is almost like a small clutch that sits on the output shaft between gears, slowing or increasing the required gear's relative speed to perform a perfect meshing of teeth within the transmission. Helical gears are used throughout and each gear on the main shaft is supported on needle rollers. That design reduces noise and improves efficiency. Transmission gears are helical gears and they have teeth cut at an angle. Helical gears run without creating gear specific sound. Reverse gears may be use straight-cut teeth's which result in a whining sound as the vehicle moves in reverse. The gearbox casing, which is ribbed to avoid distortion under load, is a lightweight die-casting aluminium alloy.

Protection is required to prevent the switch-on reverse gear in this five-speed and reverse gearbox. Some form of blocker arrangement is fitted to a gearbox to prevent the accidental engagement of reverse gear when the vehicle is moving forward. The simplest form is a spring-loaded detent. This must be overcome by the driver before the lever can be moved to the reverse position. To overcome this spring, the driver either has to lift the gear lever or exert extra pressure on it. Other schemes also exist.

Mechanical remote-control mechanism for gear change is used. The linkage used must be capable of transmitting two distinct motions: longitudinal and transverse movement. Two systems are in common use: a single rod linkage and a twin cable arrangement. During operation, movement of the engine due to torque reaction is accommodated by either using a universal joint or relying on the inherent flexibility of the cable [0.7, 0.13].

In forward wheel drive power from the engine is delivered directly with minimum mechanisms to the front wheels of your vehicle. With FWD, the front wheels are pulling the car and therefore rear wheels don't receive any power on their own. The pros of transmission and differential system in an FWD vehicle are that they typically get better fuel economy and emits less CO_2.

3.1.4 A continuously variable transmission CVT

A continuously variable transmission, also named as single-speed transmission can change seamlessly through a continuous range of effective gear ratios. The most common type of CVT operates on an ingenious and also simple two pulley system that allows an infinite variability between highest and lowest gears with no discrete steps or shifts [0.10, 0.26]. Also exists an infinitely variable transmission (IVT), which is a continuously variable transmission with an infinite ratio range up to zero, for example, due to being attached to a planetary gear set. It consists of three elements: a continuously variable transmission, a planetary gear train and a fixed ratio mechanism. In the IVT not really needing a torque converter since it can always be in gear. Another CVT system is named Toroidal TCVT. It is made up of discs and rollers that transmit power between the discs. The simplest TCVT seems to be the disk and wheel design, in which a wheel rides upon the surface of a rotating disk. The wheel may be slid along it's splined axle to contact the disk at different distances from its centre. The speed ratio of such a design is simply the radius of the wheel divided by the distance from the contact point to the centre of the disk. Friction plays an important part in frictional CVT designs. More see in Refs. [3.19, 3.20]. We will not discuss these two last systems in details here.

The variable-diameter pulleys are the basis of a CVT. Each pulley is made of two 20-degree cones facing each other, see Fig. 3.6. The belt rides in the groove between the two cones. One of the pulleys, known as the drive pulley (or driving pulley), is connected to the crankshaft of the engine. The driving pulley is also called the input pulley. The second pulley is called the driven pulley because the first pulley is turning it. Output pulley is driven pulley which transfers energy to the driveshaft. When one pulley increases its radius, the other decreases its radius to keep the belt tight. Because the two pulleys change their radii relative to one another, they create an infinite number of gear ratios - from low to high and everything in between. Continuously variable transmissions have been used in machine tools in a variety of vehicles, including small tractors for home and garden use. In all of these applications, the transmissions have relied on high-density rubber belts, which efficiency was low. That system does not transfer higher power. One of the most important advances has been the design and development of metal belts to connect the pulleys [3.21]. These flexible belts are composed of several (typically nine or 12) thin bands of steel that hold together high-strength, bow-tie-shaped pieces of metal. Metal belts don't slip and are highly durable, enabling CVTs to handle more engine torque. They are also quieter than rubber-belt-driven CVTs.

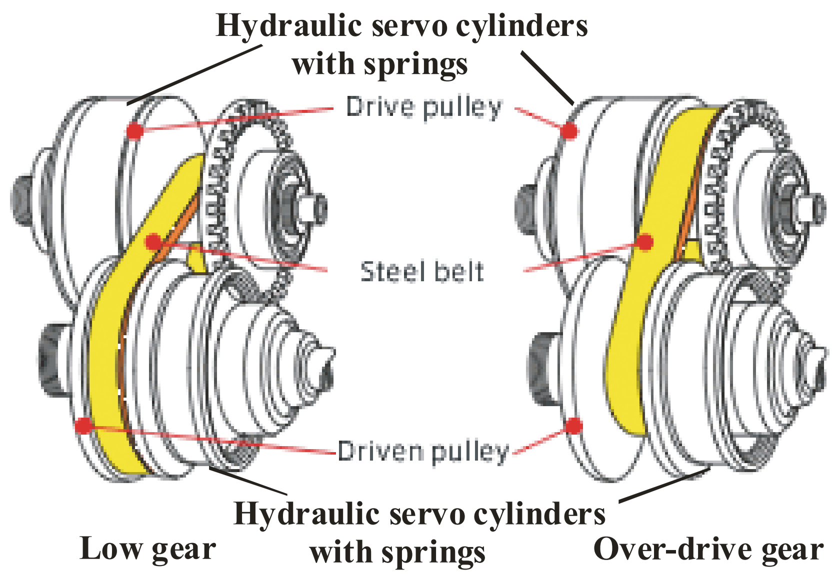


Fig. 3.6. A continuously variable transmission pulley layout at two different speeds, low and high. Adapted from [3.22].

A continuously variable transmission schematic layout is shown in Fig. 3.7. CVT transmission operates by varying the working diameter of the two main pulleys in the transmission. The pulleys have V-shaped grooves on which the connecting belt is mounted. One side of the pulley is fixed. However, the other side is moveable, operated by a hydraulic actuator. The hydraulic actuator may increase or decrease the amount of space between the two sides of the pulley. This makes the belt to ride lower or higher along the inner walls of the pulley, depending on driving conditions, in the same time changing continuously the gear ratio. Pulley widths are adjusted by oil pressure in the hydraulic actuator which responds to position of the throttle, speed, and other conditions, which are sensed by computer and other sensors.

The speed ratio setting control is achieved by a spur type hydraulic pump and control unit which supplies oil pressure to both primary and secondary sliding pulley servo cylinders. In the spur gear pump, there are two gears. It consists of a driven gear and another one that runs free contained within a pump housing. It is more effective pump than one gear.

The variation in axial spacing of the primary or driving pulley halves is controlled by a hydraulic servo cylinder see Fig.3.6. Hydraulic cylinders are actuation devices that use pressurized hydraulic fluid to produce linear motion and force. CVTs may use hydraulic pressure, centrifugal force or spring tension to create the force necessary to adjust the pulley halves.

At present, in modern cars is installed additional electric pump. It is a pump driven by the electrical motor and is employed to take care of fluid pressure and lubricate the automated transmission or continuously variable transmission during engine stop of such vehicles equipped with a Stop-Start system [3.23].

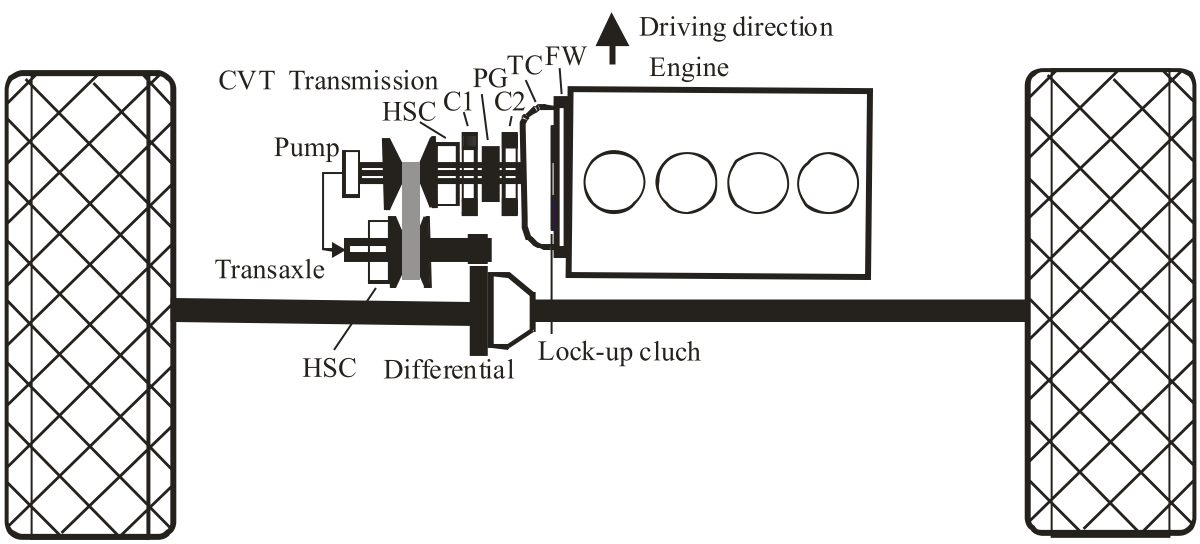


Fig. 3.7. A continuously variable transmission schematic layout. Clutches (clutch packs): C1 is forward clutch, C2 is reverse clutch. PG is planetary gear set, TC is torque converter, FW is flywheel. HSC is Hydraulic servo cylinders with springs to adjust the pulley halves.

Cars with CVT have no clutch that disconnects the transmission from the engine. Instead, they use a device called a torque converter as in automatic transmission.

A reverse gear is achieved by the use of a planetary gear set arrangement. The input shaft carries the sun gear while two row carrier set is connected to the input pulleys. Some loses exist via torque converter. To overcome these losses torque converter is equipped with a lock-up clutch that can lock the engine output to the transmission under certain conditions, as in AT.
A CVT draws top engine power from a small engine, which gives drivers quicker acceleration than standard automatic transmissions. Because of their greater ability to control the engine

speed range, CVTs produce fewer emissions. CVTs are also lighter weight than traditional automatic transmissions [0.25]. The power available from an internal combustion engine cannot be fully exploited by the finite number of gears in traditional geared selector gearboxes. With a continuously variable transmission, the engine can be operated at the ideal operating point for economy or high performance.

The CVT has its own advantage and disadvantage. At the first glance, it is a very simple gear box. However, it uses very high-quality materials, pulley, belt, special fluid ATF CVT, controlling actuators and other sensors increase the cost of CVT transmission. However, anyone who wants to have a smooth drive can choose this transmission. For the drivers who love to listen to the engine's acceleration sound in gear shifting, that car is a little tedious. The car may accelerate at the same engine speeds (rotations). To simulate conventional driving, traditional transmissions work is simulated. For this imitation, the speed range is split into a selected part 6 or 8. That is represented as gears. It can be switched on to the steering wheel via paddle shifters or via selector level position mounted vertically on the middle console, see Fig. 3.8.

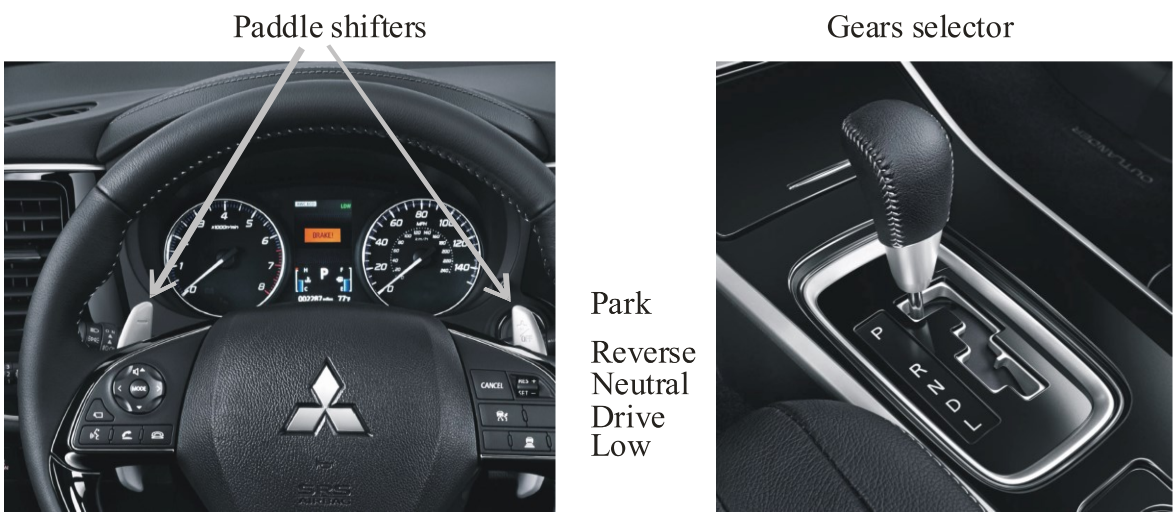


Fig. 3.8. Mitsubishi Outlander 2018 automatic transmission CVT paddle shifters and gears selector view. Adapted from [1.50].

The AT and CVT main advantage are their ease of driving. Drivers are willing to pay a premium for this type of transmission even though performance and fuel economy are slightly less to the MT. But the MT isn't always the best way for fuel economy [3.24]. A reduced performance and fuel economy are because of the lower efficiency of the AT & CVT transmission. Over the same representative drive cycle the efficiency of AT and CVT is seen to be less than the MT. Efficiency for manual is 97%, for automatic is 86%, for continuously variable transmission (with belt) is 88%. Automatic transmissions are complex mechanisms containing multiple interdependent systems typically consisting of between 500-700 parts. Manual transmissions are the highest efficiency values of any type transmission [3.25, 3.26]. AT, AMT and CVT now can achieve fuel consumption that can often be as MT.

If you want the car to do the gear changing for you, buy the car with automatic gearbox. If you want more control work of the car, better for you is to buy the car with manual gearbox.

On average, a manual transmission will cost you about a thousand dollars less than an automatic of the same model. In general, an automatic car might be better suited to those who are used to urban driving. If nothing else, not having to press the clutch on and off continuously will lessen driver fatigue. If you travel longer distances or are used to driving on faster roads, a manual car could be a better option. The fuel economy more depends on speed and driving style.

Manufacturers use many different names to describe their implementation of the various types of CVT systems. The principle of operation is common but different are management features and relations with other components of the car. It has more deals the computer control [3.27]. One of the biggest manufacturers of CVT is JACTO company [3.28]. In Table 3.3 presented few selected transmissions systems of various vehicles manufacturers.

Table 3.3. A continuously variable transmission (CVT) systems realized in vehicles.

Companies, Ref.	Marketing names	Comments
Audi, Volkswagen [3.29]	Multitronic	Multitronic with Tiptronic (using paddles) function offers a synergy of the best possible dynamics, optimal fuel utilization and the highest drive comfort
Ford [3.30]	eCVT	Hybrid is currently powered by a CVT
Honda [3.31, 3.32]	CVT, e-CVT Hybrid electric	Electric Continuously Variable Transmission (e-CVT) system to manage interactions between the two electric motors and the gasoline engine
Hyundai, Kia [3.33 - 3.35]	CVT (IVT)	Kia calls it the Intelligent variable transmission (IVT), also known as a continuously variable transmission (CVT)
Mercedes [3.36]	Autotronic	Kick-Down function: Manual control function is enabled with activation on the +/- touch selector lever (more acceleration at lower gear, equivalent sharply press the accelerator pedal right down)
Mitsubishi [3.37]	INVECS-III	It selects automatically the optimal gear ratio based on road and driving conditions. Some models are equipped with a 6-speed sports mode for a sporty, manual-like driving experience
Nissan [3.38]	Xtronic	Xtronic characterized by its adaptive shift control, which interprets driver intentions from acceleration and steering to provide optimum shift control. Coordinated control between engine and transmission delivers optimal fuel consumption and driving performance
Subaru [3.39]	Lineartronic	CVT drive is smooth. It's the world's first longitudinally mounted system for AWD
Toyota [3.40, 3.41]	CVT, Direct Shift -CVT (DCVT)	DCVT combines features from an automatic transmission, a CVT, and a manual transmission

3.2 steering systems

Steering system in automobiles consists of steering wheel, gears, linkages, and other components used to control the direction of a vehicle's motion. Because of the friction between the front tires and the road, especially in parking, more power is required to turn the steering wheel. The function of a steering system is to convert the rotary movement of the steering wheel into the angular turn of the front wheels on the road. The steering wheel movement transmitted to the wheels through a system of pivoted joints. There are two mechanical steering systems in common use: the first uses the steering box (worm and roller gearbox) and the second uses the rack and pinion. Most modern cars have some form of power assistance, typically hydraulic or electric, sometimes named as electronic. Neglecting innovations in steering it still requires physical and careful efforts [0.10, 3.42-3.44].

Rack-and-pinion steering is quickly becoming the foremost common sort of steering on cars, small trucks and SUVs. It's actually a reasonably compact and simple mechanism. The rack-and-pinion gearset is enclosed in a metal tube, with each end protruding from the tube. A rod, called a tie rod, connects to each end of the rack.

Today's automobiles mostly use the electronic systems and under development is an electronic steering mechanism named a steer-by-wire. It aims to eliminate the physical connection between the steering wheel and the driving wheels of a car by using electrically controlled motors or hydraulic systems to vary the direction of the wheels and to supply feedback to the driver. That systems are actuals for self-drive cars. Problem exist, such a system is against the law in most jurisdictions for passenger or commercial vehicles.

Initially we debate simplest mechanical steering systems. There exist a variety of steering systems. But we present only a few systems which are more actual for passenger cars. That systems we group in two parts. The first is known as a recirculating ball (nuts) steering or worm and roller system (in simple case, without balls). The second is understood as a rack and pinion steering system, see Fig. 3.9. The first system is more actual for rear-wheel-drive cars, the second is compact, precise and more actual for front wheel drive cars. Both systems could also be powered with hydraulic-mechanical, hydraulic-electric motor, or directly electrical motor.

Within the first case at the base of the steering column there's a worm gear inside a box (also called steering gearbox). The worm may be a threaded cylinder sort of a short bolt. Imagine turning a bolt which holding a nut thereon. The nut would move along the bolt. Within the same way, turning the worm moves anything fitted into its thread.

The nut system has hardened balls running inside the thread between the worm and the nut. Because the nut moves, the balls roll out into a tube that takes them back to the beginning. It's called a recirculating-ball system.

In the recirculating ball system, the worm moves a drop arm linked by a track rod to a steering arm that moves the nearest front wheel. In recirculating ball steering, the thread between the worm and nut is filled with balls. A central track rod reaches to the other side of the car, where it is linked to the other front wheel by another track rod and steering arm. A pivoted idler arm holds the far end of the central track rod level. For different cars arm layouts may vary.

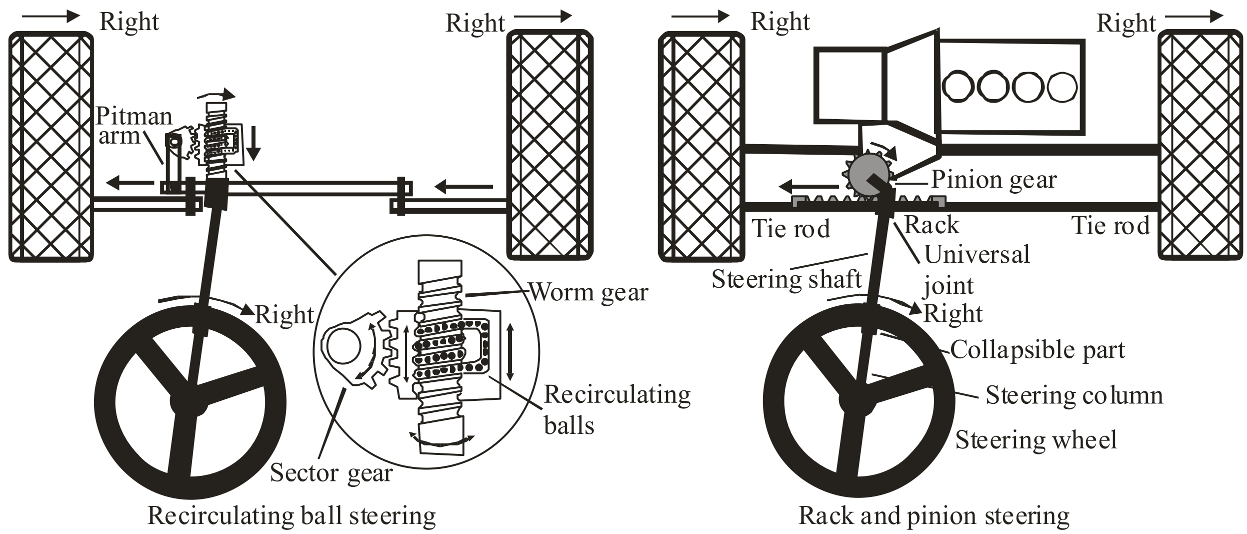


Fig. 3.9. Recirculating ball steering (the steering gearbox) system (left) and Rack and pinion steering system (right).

The mechanism of this system is installed in the steering gearbox. It is the older and more heavy-duty type of steering gear. It may be used for manual steering or equipped with a power assisted steering system. When the steering wheel is turned, the steering gear, whether power assisted or not, turns the pitman arm, which causes the wheels to turn. The pitman arm doesn't get its name from an individual, but rather from sawmill slang. The man who was in a pit below a log who pulled a saw through the wood to create boards was known as the pitman. Recirculating ball steering is used on many trucks and SUVs and today.

Rack and pinion steering provide a gear reduction, making it easier to turn the wheels. At the base of the steering column there's a little pinion (gear wheel) inside a housing. Its teeth mesh with a straight row of teeth on a rack - an extended transverse bar, see Fig. 3.9 (right).

Turning the pinion makes the rack to move from side to side. The ends of the rack are coupled to the road wheels by rack tie rods. This technique is simple, with few moving parts to become worn or displaced, so its action is precise. The pinion is closely meshed with the rack, in order that there is no backlash within the gears. This provides very precise steering. A universal joint within the steering column allows an easy connect steering wheel with the rack.

3.3 Power assisted steering systems

There are two types of power assisted steering systems: hydraulic and electric/electronic. The hybrid or in other words Electro-hydraulic power steering system was also realized. In principle Electro-hydraulic power steering is an extension of the hydraulic power steering.

Power steering systems amplifies the torque that the driver applies to the steering wheel. Conventional power steering systems are hydraulic power systems (HPS). Hydraulic power steering systems work by using a hydraulic pressure to multiply force applied to the steering wheel inputs to the vehicle's steered (usually front) road wheels. The hydraulic pressure typically comes from a rotary vane pump driven by a vehicle's engine. The engine drives a pump that supplies oil under high pressure to the rack or steering box. Valves in the steering rack or box open whenever the driver turns the wheel, allowing oil into the cylinder. The oil works a piston that helps push the steering in the proper direction. When the driver stops turning the wheel, the valve shuts and the pushing action of the piston stops. The power only assists the steering. The steering wheel is all time linked to the road wheels in the usual way. This is a safe driving insurance. If the power fails, the driver can still steer, but the steering becomes much heavier. Generally, a power steering system uses the power of the engine to drive the oil pump that generates hydraulic pressure.

The EPAS acronym stands for electric power assisted steering system or shortly electrical power steering (EPS). This system replaces the hydraulic pistons and pump with a motor to push the steering rack as the drivers turn the wheel.

The electric motor can be column mounted or positioned on the rack itself. At present steering systems come with a more simplified electric motor designed to augment the steering commands made by drivers. Also, the EPS system doesn't use all time power from the engine (battery) as the hydraulic systems do. Commonly, the electric power steering system is more efficient and more flexible.

Between the hydraulic and electric types of power steering, there's a hybrid of the two systems, called electrohydraulic or named an electric hydraulic power steering (EHPS). That is a power steering system that uses an electric motor to generate the hydraulic pressure and reduces the power required to operate the steering wheel [3.45]. It operates like a hydraulic-assist system. In that case the hydraulic pressure is caused by an electric motor driving pump. It works independently of engine, and may temporarily use energy from battery if required.

For passenger vehicles, electric power steering is becoming much more common. EPS eliminates many HPS components such as the pump, hoses, fluid, drive belt, and pulley. For this reason, electric steering systems tend to be smaller and lighter than hydraulic systems.

EPS systems have variable power assist, which provides more assistance at lower vehicle speeds and less assistance at higher speeds. They do not require any significant power to operate when no steering assistance is required. For this reason, they are more energy efficient than hydraulic systems.

The EPS electronic control unit (ECU) calculates the assisting power needed based on the torque being applied to the steering wheel by the driver. For calculations also used the steering wheel speed and position. That information may be sent from torque sensor, which simultaneously registered speed and position of steering wheel. For calculations the vehicle’s speed is used too. The EPS motor rotates a steering gear with an applied force that reduces the torque required from the driver.

Nowadays, there are different EPAS systems on the market, which are used according to the vehicles boundary conditions and the vehicle manufacturer’s technological logic.

Some technical data may be useful to know for car consumer. There are four forms of EPS, based on the position of the assist motor (electric). They are the column assist type (C-EPS), the pinion assist type (P-EPS), and two other rack assist R-EPS) systems. One of them named rack parallel type electric power steering (RP-EPS) and other named rack-direct-drive type electric power steering (RD-EPS) [3.46-3.48]. The list of different EPS is presented in Table 3.4. Two of them schematically are shown in Fig. 3.10.

The column-based C-EPS includes a power assist unit, torque sensor, and controller. All of them are installed on the steering column.

In the P-EPS system, the power assist unit is connected to the steering gear's pinion shaft. This type EPS works well in small cars.

The R-EPS type system has the assist unit connected to the steering gear (screw and nut). R-EPS systems may be used on larger vehicles, it is stronger and more powerful.

Table 3.4. List of electrical power assist steering systems [3.46-3.48].

Electrical power steering system	Acronym	Comment
Column type electric power steering	C-EPS	Power assist unit is located in the driver's cab. In case of steering C-EPS, the electric motor, control unit and the torque sensor are integrated into the steering column. System used primarily in small and compact vehicles. Popular
Pinion type electric power steering	P-EPS	Located inside the engine compartment. Compact design, integrates the electric assist mechanism into the primary steering gear pinion shaft. Popular
Dual pinion type electric power steering	DP-EPS	Primary pinion to be optimized for vehicle dynamics and performance and a secondary pinion to be optimized for assist. Mainly used on mini-vehicles and small-class cars. Requires 2 pinions and 2 racks. Simple to understand operation principle
Rack parallel type electric power steering	RP-EPS	A pinion on the motor shaft drives a toothed belt, which transfers the torque to the nut of a ball screw drive, whose spindle is on the steering rack. Excellent steering feels with high rigidity and superior dynamic performance. Easier to install
Rack-direct-drive type electric power steering (it is also assisting system)	RD-EPS	With this system, the rotor of the electric motor is seated directly on the ball screw nut. As the system includes only one transmission stage, the electric motor must provide a very high torque. Systems are used in vehicles with high axle loads and a correspondingly high actuation force requirement. However, they are still not widely used today
Electronically controlled variable-gear-ratio steering	E-VGR	Combines vehicle stability and steering performance. Increasing steering-angle ratio at low speed
Combination: (E-VGR)+(RD-EPS)	(E-VGR)+(RD-EPS)	Variable steering-angle ratio system, combining vehicle stability and steering

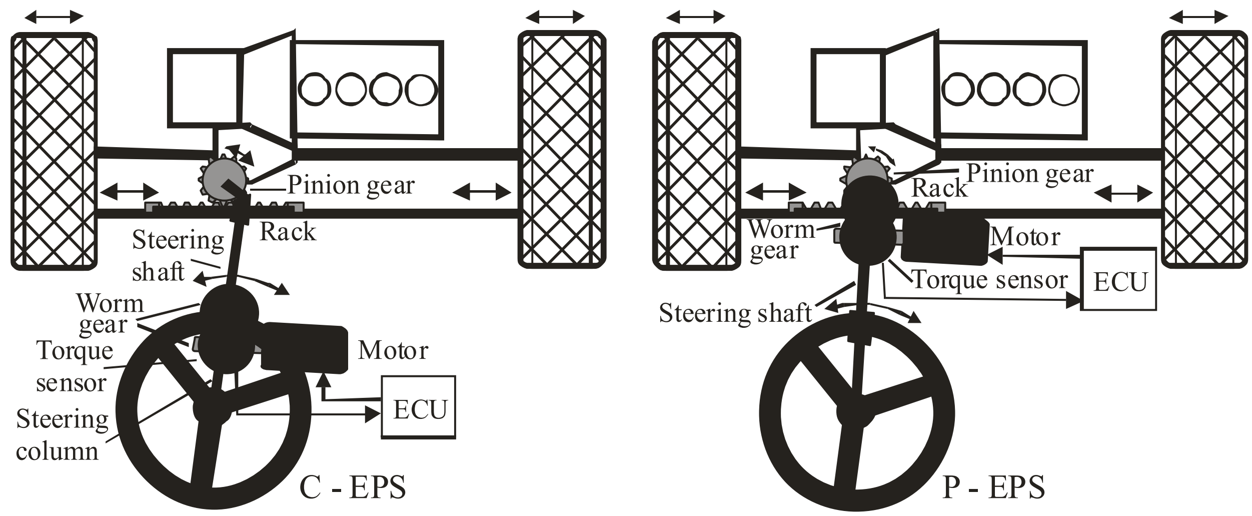


Fig. 3.10. Schematic drawing column (C-EPS) and pinion (P-EPS) type electric power steering systems. The ECU is EPS electronic control unit.

Short comments of various electrical power assist steering systems included in Table 3.4. Electronically controlled variable steering-angle ratio system (E-VGR) combines vehicle stability and steering performance. Steering performance improved by increasing steering-angle ratio at low speed. Straight line driving stability is improved by decreasing steering-angle ratio at high speed. Vehicle stability is improved by activating low friction torque. The function of this product is also used in the automotive collision avoidance assist system, steering control while vehicle is skidding, and lane keeping assist system. Good results are shown of the combination of E-VGR with RD-EPS.

The efficiency advantage of an EPS system is that it powers the EPS electric motor only when necessary. These systems can be tuned in by simply modifying the software controlling the ECU. There are no problems to adapt selected steering system for some model of vehicle. An additional advantage of EPS is its ability to compensate for one-sided forces such as a flat tire. It is also capable of steering in emergency manoeuvres in conjunction with electronic stability control.

A typical EPS steering application uses a bidirectional brushless motor, sensors and electronic controller to provide steering assist [3.49-3.53]. Nidec Corporation, Bosch, Johnson Electric, Denso Corporation, and Mitsubishi Electric are some of the major suppliers of motors for EPS systems in the automotive industry [3.54].

The motor will drive a gear that can be connected to the steering column shaft or the steering rack. Sensors located in the steering column measure steering wheel torque, turning rate and angular position. The steering wheel is included as a hand wheel in the service information. The torque, turning rate and position inputs, also vehicle speed signal, and other inputs are interpreted in the electronic control module. The controller returns the proper amount of polarity and current to the motor. Other signals as engine rotation speed and signals from chassis control systems such as ABS and electronic stability control (ESC) may be included in steering control algorithm.

The brushless motor uses a permanent magnet rotor and three electromagnetic coils (three phases) to propel the rotor [3.51]. Most applications use a motor worm gear to drive the gear on the steering shaft or rack. The brushless bidirectional permanent magnet motor and gear perform the same function as the power cylinder in a hydraulic system. Motor uses three electric alternating current (AC) phases. Supply of motor is electronic generator-converter which changes direct current (DC) to AC, also may change order of phases and rotation direction. It leads from physics laws. The electric current does not need to be strictly sinusoid, but it can also be impulse.

In current-day systems, there is always a mechanical connection between the steering wheel and the steering gear. For safety reasons, it is important that a failure in the electronics never result in a situation where the motor prevents the driver from steering the vehicle. EPS systems incorporate fail-safe mechanisms that disconnect power from the motor in the event that a problem with the ECU is detected.

We overview few prognoses of the future in the power steering. The next step in electronic steering may be to remove the mechanical linkage to the steering wheel and convert to pure electronically controlled steering, which is referred to as steer-by-wire or drive-by-wire system [3.55]. These systems would completely eliminate the mechanical connection between the steering wheel and the steering, replacing it with the electronic control system.

Second step self-driving car. The computer driving system would contain GPS and surrounding sensors that tell the car what the driver system is doing with the car wheels. System also will be equipped with series motors, other actuators to drive a car and to get information feedback what the car is doing. The output from computer would be used to control a motorized driving system. A lot of effort is being put into those things right now. These systems must first guarantee safety.

3.4 Anti-lock braking system (ABS)

An anti-lock braking system (ABS) is a safety anti-skid braking system used on aircraft and on land vehicles, such as cars, motorcycles, trucks and buses. ABS operate by preventing the wheels from locking up during braking, thereby maintaining high friction between wheels and road surface [1.2, 3.56-3.59]. An anti-lock braking system is one of the best innovations in vehicle driving.

Stopping a car in a hurry on a slippery road can be very challenging. Anti-lock braking systems take a lot of the challenge out of this. In fact, on slippery surfaces, even professional drivers can't stop as quickly without ABS as an average driver can with ABS. All anti-lock brake systems are designed to control tire skid and maintain vehicle stability and steering control during panic stopping. By continually monitoring the relative speeds of the wheel assemblies, the processor is able to respond to a skid situation by momentarily reducing the pressure to the brake assembly on the affected wheel(s). By rapidly pulsing the affected brake circuits, the braking load is reduced and allows traction to be regained, thus preventing lock up. Once the need for anti-lock passes, the system returns to normal brake operation. In the Table 3.5 are listed components of conventional and ABS braking systems.

There are few different ABS systems. The foremost advanced is four channel, four sensor system, which has a wheel speed sensor on each wheel and separate valves to control brake pressure to each wheel. Next is the three- sensor, three valve system, which has a speed sensor and controlling valve for each of the front wheels and single channel and valve for both rear wheels. The speed sensor for the rear wheels is located in the rear axle. The simplest system is the single channel, and one speed sensor, located in the rear axle system that operates on both rear wheels. This technique is found on pickup trucks.

Table 3.5. Brake system elements in conventional and ABS cases.

Conventional	ABS	Comment
Brake pedal	Brake pedal	Press with your foot: the brakes are activated and the brake light comes on (rear of the car)
Brake servo unit (booster)	Brake booster	Vacuum brake servo, multiply the drivers pedal effort
Master cylinder	Master cylinder	The main source of pressure in a hydraulic braking system
Brake-fluid* reservoir	Brake-fluid* reservoir	Stores vehicle's brake fluid*
Front wheel brakes (disc brakes) with brakes cylinders	Front wheel brakes (disc brakes) with brakes cylinders	Hydraulic
Rear wheel brakes (drums or discs brakes) with brakes cylinders	Rear wheel brakes (drums or discs brakes) with brakes cylinders	Hydraulic
Braking-force reducer		Reduce the pressure on the rear axle on braking
	Wheel-speed sensors	Four, for all wheels
	Hydraulic modulator Pump (electric), valves (solenoids)	Optimizes brake pressure on each wheel. Pressure back up, distribute pressure
	ABS control unit	Microprocessor/Computer
	ABS off warning lamp	Lighting: Shortly - test, Continuously - fault
		
*- Always refer to vehicle owner's manual for what the manufacturer recommends or warns against. As a rule, vehicles equipped with anti-lock brakes (ABS) should not use DOT 5 brake fluid.		

DOT 5 brake fluid is silicone based. DOT 3 (standard) and DOT 4 (heavy-duty), also DOT 5.1 are glycol-based. It can be distinguished from conventional brake fluids by its purple colour (which comes from a dye). Silicone does not absorb moisture. DOT 5 brake fluid does not become contaminated with moisture over time as conventional DOT 3 and 4 brake fluids do. Silicone is also chemically inert, nontoxic and won't damage paint like conventional brake fluid. It also has a higher boiling point. Silicone also has slightly different physical properties and compressibility, making it unsuitable for ABS systems calibrated to work with DOT 3 or 4 brake fluid.

The brake fluids are available in various colours like brake fluid DOT 3 is available in clear, Pale Yellow, Blue & Crimson Red colour. Similarly brake fluid DOT 4 is available in Clear, Pale Yellow & Crimson Red colour. Brake fluid DOT 5.1 is available Clear, Pale Yellow & Blue colour. Brake Fluid DOT 5 is available in Purple & Violet colour. It is important that colour is not a criterion to distinguish between the different types of brake fluids. The colour is added in brake fluid to detect the leakage. Colour does not affect the quality of brake fluid [3.60-3.61].

Best way to know about brake fluid used in your car is to read manual. For example, Mitsubishi ASX 2018 recommendations. Use brake fluid conforming to DOT 3 or DOT 4 from a sealed container. The brake fluid is hygroscopic. Too much moisture in the brake fluid will adversely affect the brake system, reducing the performance. Take care in handling brake fluid as it is harmful to the eyes, may irritate your skin and will damage painted surfaces. Wipe up spills immediately. If brake fluid gets on your hands or in your eyes, flush immediately with clean water. Follow up with a doctor as necessary [2.110].

We will comment on the car's braking mechanisms a little more. The brake booster (brake servo unit) is inserted between the brake pedal mechanism and the hydraulic master cylinder. The brake booster uses vacuum from the engine to multiply the force that your foot applies to the master cylinder. The vacuum can be generated in two methods, dependent on the type of internal combustion engine, or another reason, in a case of electric vehicle. In petrol engines, the manifold vacuum is used. In vehicles with turbo charged diesel engines or in electric/hybrid vehicles a separate vacuum pump is used. The vacuum pump can be driven mechanically from the engine or by electric motor. The vacuum is transferred to non-collapsible vacuum pipes and stored in an empty balloon with non-return valve. Most stops use approximately 20 to 40% of the atmospheric pressure differential to stop the vehicle. In principle at high-altitude places may not be problematic for the booster work. Because at 4 km altitude the pressure loss is only of about 40%.

There are four main components to an ABS system. They are speed sensors, hydraulic pump, which is driven by electric DC motor, hydraulic valves (actuators) and electronic controller. Most important moment for the anti-lock braking system is to know what and when a wheel to lock up. The speed sensors, which are located at each wheel, or in some cases in the differential, provide this information. There is a valve in the brake line of each wheel brake controlled by the ABS. Valve controls force on the brake. The controller is a computer in the car. It collects information from the speed sensors and controls the hydraulic valves. For ABS is used the pressure modulation system. The number of the valves differs from model to model due to additional functionalities and the number of brake channels.

When the ABS system is in operation you will feel a pulsing in the brake pedal. That is completely normal. This action occurs from the rapid opening and closing of the valves. ABS system can cycle up to 15 times per second.

ABS braking system include all conventional braking systems. On many vehicles, the brakes should still operate normally when ABS warning light is on, but the antilock function won't work. On some vehicles, though, braking ability will be reduced if the antilock system malfunctions, and stability control and traction control (on vehicles with those features) might also be disabled.

An ABS warning light usually triggers a trouble code that can be read with a diagnostic tool to help mechanics obtain the problem.

3.5 Brake assist system

Brake assist is an active vehicle safety feature designed to provide greater brake force by assisting brake pedal actuation during emergency braking [3.62, 3.63]. Brake assist is also named by other names including Emergency Brake Assist (EBA) and Predictive Brake Assist (PBA). The various names are significant because although all brake assist systems have an equivalent purpose, some of them are designed differently.

Brake Assist measures the wheel speed and force of the brake application to determine whether the driver is attempting an emergency stop. If such an emergency is decided, the system applies additional brake pressure to permit the driver to use full advantage of the Antilock Braking System, which prevents wheel lock up.

Brake assist is beneficial whenever drivers must brake hard to make an emergency stop. For instance, animal on road. Brake assist usually works together with ABS to help braking as effective as possible while avoiding wheel lockage.

Brake assist systems at present are electronic. In old vehicles they were organized mechanically. Electronic brake assist systems use an electronic control unit (ECU) that compares instances of braking to pre-set thresholds. If a driver pushes the brake down hard enough and fast enough to surpass this threshold the ECU will decide that there's an emergency and boosts braking power. More of those systems are adaptable, which suggests they're going to compile information of a few driver's particular braking style and to decide when there's a fast break on the car.

3.6 Electronic brake distribution (EBD)

Electronic Brake Distribution or Electronic Brake Force Distribution (EBD or EBFD), also Electronic Brakeforce Limitation (EBL) is that extension of the ABS. This is the system that checks the speed and acceleration or deceleration of each wheel to estimate the quantity of load on the wheels. This technique demonstrates how important a measure of speed of all wheels. The EBD adjusts the valves on the hydraulic lines of the brakes and distributes the braking force accordingly. EBD is the most vital part of the braking system.

This technology reduces stopping distances by detecting passengers or heavier loads in a car, then automatically increasing the rear-braking force to deliver predictable and consistent stopping performance. Older cars were equipped with the mechanical brake force regulator. At the present EBD is that the part of the ABS and it is as standard [3.64, 3.65].

The electronic brake distribution, neglecting of different names, is an automobile brake technology that automatically varies the amount of force applied to each of a vehicle's wheels, depending on road conditions, speed, loading, etc. Always including anti-lock braking systems, EBD can apply more or less braking pressure to every wheel so as to maximize stopping power whilst maintaining vehicular control. Typically, the front of the car carries the foremost weight and EBD distributes less braking pressure to the rear brakes therefore the rear brakes do not lock up and don't cause a skid. In some systems, EBD distributes more braking pressure at the rear brakes during initial brake application before the consequences of weight transfer become apparent. Electronic brake distribution is an active vehicle safety feature designed to form braking as efficient as possible. EBD distributes braking power consistent with which wheels are braking now effectively. For instance, even as heavy braking causes a driver's body to move forward, slamming on the brakes also pushes the load of the vehicle forward therefore the front wheels bear the foremost weight. When this happens, the rear wheels might not have enough grip on the road. This might cause the rear wheels to spin and eventually lock up. Locked-up back wheels increase the danger. This will result in longer stopping distances and an increased risk of collision. EBD reduces these dangers by automatically balancing the brake force applied to every wheel consistent with the general weight distribution of the vehicle. The safety systems not only prevent wheel lockage by reducing brake force to spinning wheels, but can also allocate more brake-force to wheels that it detects are braking not enough effectively.

With EDB, the distribution of braking forces between the front and rear wheels are optimized and the maximum braking force is ensured no matter of load conditions. For instance, when many passengers are carried within the vehicle, the load on the rear wheels is increased. During emergency braking with many passengers, EBD recognizes this condition and increases the brake force on the rear wheels.

EBD is usually installed with anti-lock braking systems (ABS) and works very similarly to ABS. The important difference between EBD and ABS is that while both systems prevent wheels from locking, EBD can also redistribute brake-force consistent with which wheels are performing the braking better.

EBD systems are usually made from several components:

Speed sensors that monitor the rotational speed of each wheel;

Brake-force modulators that increase or decrease brake-force to every wheel;

An acceleration/deceleration detector that monitors changes within the vehicle's forward and side-to-side speed;

A yaw sensor that monitors a vehicle's side-to-side movement;

An electronic control unit (ECU) that compiles information from all the sensors and provides commands to the brake-force modulators.

As with modern ABS setups, the brake-force modulators and ECU are attached together, so while they perform different functions, they seem as together unit. The ECU monitors each wheel's responsiveness to the brake, then tailor the quantity of brake force applied to each wheel. The EBFD system senses that one among the wheels is close to lock, or that the car is swaying an excessive amount of from side-to-side, it redistributes brake force to get optimal braking power.

3.7 Electronic stability control (ESC)

Electronic stability control (ESC), also mentioned as Electronic stability program (ESP), Dynamic stability control (DSC) or Active stability control (ASC) is a computerized technology that improves a vehicle's stability by detecting and reducing loss of traction [3.59, 3.66, 367]. However, vehicle manufacturers may use other different trade names for ESC.

When ESC detects loss of steering control, it automatically applies the brakes to assist steer the vehicle where the driver intends to travel. Braking is automatically applied to wheels individually, like the outer front wheel to counter over-steering or the inner rear wheel to counter under-steering. Some ESC systems also reduce engine power until control is regained. ESC doesn't improve a vehicle's cornering performance. That helps to minimize the loss of control.

When the system detects that proper grip cannot be maintained at each tire while driving on slippery road surfaces, the braking force is applied at one or more wheels and the engine output also is adjusted to assist the driver maintain control. In addition, sensors monitor the tire traction and work with the anti-lock braking system (ABS) to counteract slipping on wet/snowy roads.

Electronic stability control is a vitally safety feature designed to reduce the amount and severity of automobile crashes that result from a loss of control. ESC provides traction and anti-skid support in cases of over-steering and under-steering. The over-steering occurs when the vehicle continues to turn beyond the driver's steering input because the rear end is sliding outwards. Under-steering occurs when the vehicle turns less than the driver's steering input because the wheels have insufficient traction. Few examples are shown in Fig. 3.11.

Stability control functionality and realization is related with such operations. ASC uses onboard sensors to analyse the vehicle's motion and identify lateral wheel slippage. By controlling engine output and controlling braking to the acceptable wheels. ASC helps maintain stability and traction control. If lateral rear wheel slippage, braking force is applied to the outer front wheel to prevent spin-out. If lateral front-wheel slippage, braking force is applied to the inner rear wheel to prevent front-end drift.

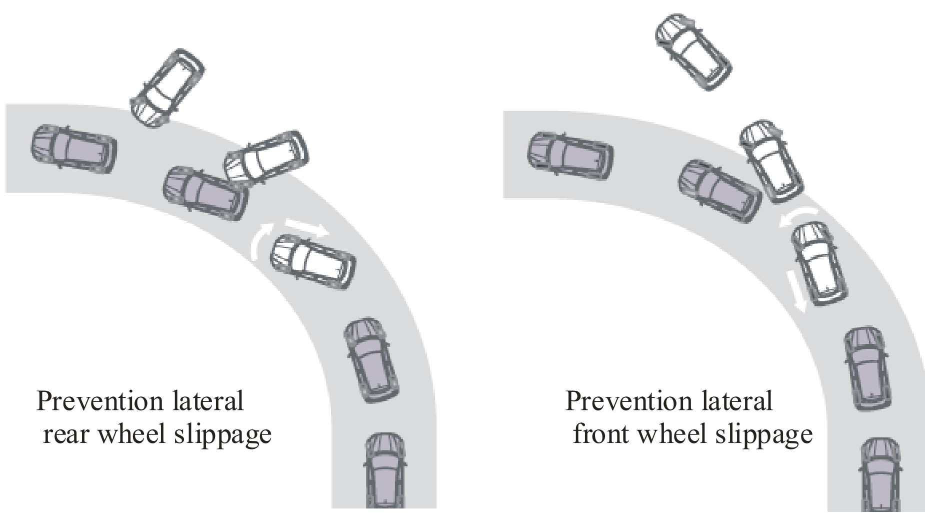


Fig 3.11. Operations of Active stability Control System (ASC). Adapted from [3.3].

ESC allows drivers to retain control of their vehicles in situations where this is very difficult or impossible to do. A standard way that drivers lose control is by steering too sharply, which shifts the centre of gravity of the vehicle and increases the danger of rolling over. Additionally, poor road conditions that make skidding and sliding more likely also increase the danger of over-steering and under-steering. ESC reduces the danger of losing control in many fairly common driving situations. An unanticipated event forces you to swerve quickly, for example, an animal runs on the road or a car pulls out of a driveway. Also, maybe you approach a curve too quickly and must to steer more aggressively. Your wheels grabbed a piece of icy road and as a result your car starts to spin too.

ESC systems are made from several subcomponents that are monitored and controlled by an electronic control unit (ECU). The subcomponents include: a yaw sensor that measures the vehicle's side-to-side movement; wheel speed sensors that measure the speed of rotation for every wheel; a steering angle sensor that monitors your steering input, and; a hydraulic unit that increases braking or decreases wheel speed. The ECU continually updates information from these sensors and compiles the info to work out if any difference exists between the driver's steering input and the vehicle's actual direction of travel. The wheel speed sensors tell the ECU whether some wheels are spinning more quickly than others, a sign that those wheels are losing traction. If the ECU senses that something goes wrong, it'll direct the hydraulic unit to use more brake force to certain wheels so as to bring the vehicle back under the driver's control. Some ESC systems also initiate a reduction in engine power. Don't worry, at first moment you may think that you have lost the accelerator control function. If the ECU detects a case of over-steering, it'll automatically send an order to use the front outside brake to counter the loss of traction affecting the rear wheels. If under-steering occurs, the within rear brake are going to be applied to encourage the vehicle to still turn within the direction of the driver's steering input.

You can switch ESC Off. After restarting engine ESC automatically returns to initial default position. Switch off can help in car stuck situation. However, disabling ESC all time is as dumb as driving without seatbelts.

3.8 Traction control system

A traction control system (TCS), Active traction control system (ATC), also known as ASR, from German: Antriebsschlupfregelung - Drive slippage regulation. When that system to stop functioning, illuminating the TCS warning light named Traction control lamp (TCL). Traction control (TC) helps limit tire slip in acceleration on slippery surfaces [3.68, 3.69]. Most of today's vehicles employ electronic controls to limit power delivery for the driver, eliminating wheel slip and helping the driver accelerate under control.

Traction control is an active vehicle safety feature designed to help vehicles make effective use of all the traction available on the road when accelerating on low-friction road surfaces. When a vehicle without traction control attempts to accelerate on a slippery surface like ice, snow, or loose gravel, the wheels are liable to slip. The result of wheel slip is that the tires spin quickly on the surface of the road without gaining any actual grip, therefore the vehicle does not accelerate. Traction control activates when it senses that the wheels may slip, helping drivers make the most of the traction that is available on the road surface. Traction control is used to help drivers accelerate on slippery or low-friction conditions.

Traction control works similarly to ABS and is often considered as a supplement to existing ABS setups. In fact, traction control uses the same components as ABS: wheel speed sensors that monitor the speed of rotation of the front or all four wheels; a hydraulic modulator that pumps the brakes, and an electronic control unit (ECU) that receives information from the wheel speed sensors and may send commands to actuators.

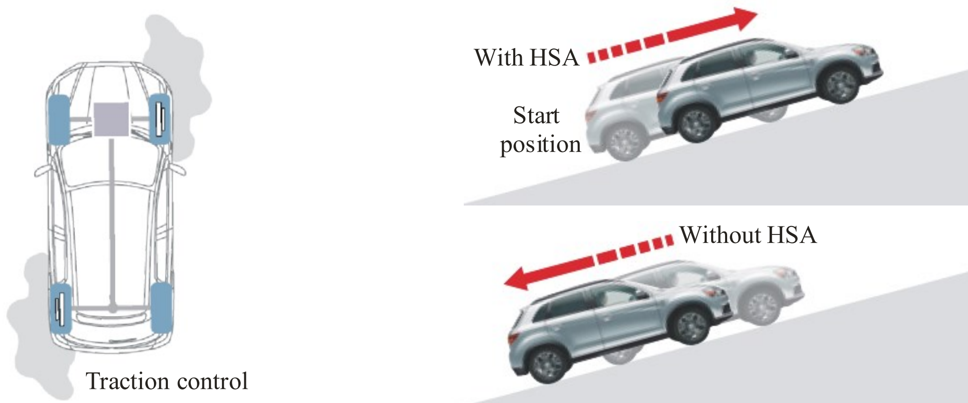


Fig. 3.12. Operation of The Traction control system (left) and The Hill start assist system (right). Adapted from [3.3].

Modern ABS and traction control systems are setup with the ECU and the hydraulic modulator installed together. They have different functions, but they are physically one unit.

The ECU continually checks whether some wheels are spinning faster than others. It is an indicator that the wheel is losing traction. When possible, wheel slippage is detected, the ECU indicates the hydraulic modulator to apply and release the brake to reduce the speed of the wheel's rotation, see Fig. 3.12. In really the control is more complex.

Some traction control systems also reduce engine power to wheels that are about to slip. Once the wheel has regained traction, the system returns to monitoring wheel speed and comparing the rotational speed of the vehicle's wheels.

In a vehicle that uses reduced engine power to control the rotation of the slipping wheels, drivers may experience a pulsation of the gas pedal when the traction control is active. This pulsation is normal and is not an indication that something is wrong with the traction control system.

3.9 Hill Start Assist HSA

The Hill Start Assist (HSA) makes it easy to start on a steep uphill slope by preventing the vehicle from moving backwards [3.70-3.72], see Fig 3.12. It keeps the braking force for approximately 2 seconds when you move your foot from the brake pedal to the accelerator pedal. The system also called hill start control, or Hill hold.

HSA is an electronic parking brake, which is directly connected to the main brakes and the ESC system. It automatically prevents the vehicle from backsliding on inclines by activating the normal brakes.

The hill start assist is quite simple. This is a purely computer program issue. No additional mechanical components necessary to make it work.

So, the main components involved are the car's ECU, existing braking system, but it requires a very high-performance sensor for the measurement of the longitudinal inclination of the car. The inclination sensor detects when a car comes to a halt at an angle, sends this information to the ECU, which then applies pressure to the brakes to keep the car firmly in place.

While the vehicle is stationary, the driver will likely keep his foot firmly on the brake pedal, but the important bit happens once the foot is removed from the middle pedal. With the clutch depressed and the foot removed from the brake, a car without hill start assist would immediately roll back. Hill start assist overcomes this by buying you a few precious seconds once you remove your foot from the brake, which gives you time to apply the right amount of throttle to get the car moving forward. It does this by still applying pressure to the brakes, even though the driver's foot has been removed from the pedal. This system is not very perfect.

The hill start assist also operates when reversing on an uphill slope. In each particular case, please refer to the Owner's manual for your car.

3.10 Indirect tire pressure monitoring

The purpose of the tire pressure monitoring system (TPMS) in your vehicle is to warn you that a minimum of one or more tires are significantly under-inflated, possibly creating unsafe driving conditions. The TPMS low tire pressure indicator may be a yellow symbol that illuminates on the dashboard instrument panel of the shape of a tire cross-section. The monitoring tire pressure are often realized through direct or indirect measurements [3.73-3.75]. An indirect TPMS system uses an ABS system to monitor the speed of the wheel so as to record tire pressure readings correctly.

Indirect TPMS don't use physical pressure sensors but measure air pressures by monitoring individual wheel rotational speeds and other signals available outside of the tire itself. Indirect TPMS systems are based on the principle that under-inflated tires have a rather smaller diameter and hence higher angular velocity than a correctly inflated one. These differences are measurable through the wheel speed sensors of ABS/ESC systems. In new generation indirect TPMS also can detect simultaneous under-inflation in up to all or any four tires using spectrum analysis (digital with car computer) of individual wheels, which may be realized in software using advanced signal processing techniques.

Indirect TPMS cannot measure or display absolute pressure values, they're relative by nature. Indirect TPMS are considered more inaccurate, but they are simple. Temperature variations can cause pressure variations of an equivalent order as sensitivity and lead to mistake in interpretation. Temperature problem is solving in direct TPMS. Without considering some accuracy problems, the indirect TPMS remains attractive for its simplicity.

Direct TPMS employ pressure sensors on each wheel, either internal or external. The sensors physically measure the tire pressure, also temperature in each tire and report it to the vehicle's instrument cluster or a corresponding monitor. About it more are going to be presented in sensors section, Chapter 6.

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Chapter 4 Electrical and Electronic systems

Commonly electrical and electronic systems are based on physics, engineering and technology. The systems are used for handling of electrical circuits. That involve active electrical components like vacuum electronics as light bulbs, halogen xenon emission lamps, solid state electronics as transistors, diodes, light emitting diodes, lasers and integrated circuits. At present it is important wireless communication, navigation, safety and security technology including electromagnetic (light, infrared, radio frequency) and ultrasound (acoustic) waves.

Automotive electric and electronics systems utilized in vehicles, including engine management, ignition, car controllers, actuators and computers (more commonly speaking telematics), in-car entertainment systems (audio, video) and other important elements such as control, lighting and signalization systems partly are going to be presented and discussed in this chapter.

4.1 Introduction to Car Electrical System

Every car with internal combustion engine has an electrical system that consists of three very important components: the battery, the starter, and the alternator They are interconnected to each other by electric wires, and in a modern car their work is controlled electronically. Hybrid and electrical vehicles are equipped with electric motors and electronic converters which transforms DC (direct current) to AC (alternating current). For the traditional vehicle the battery provides electric energy to the starter. When a battery requires energy, alternator gives it to charge a battery of car. If one of these parts is not working properly, your car does not start to run.

Battery is one of important element to start driving. Until your vehicle engine does not work, your battery is providing the car's entire electrical current. This includes lighting and the current to the ignition and fuel systems, which are responsible for creating the combustion necessary for your car engine to function.

Starter is DC electric motor. While the battery supplies the power to start your vehicle, the starter begins rotate engine's crankshaft. The battery supplies for few seconds high power of few kilowatts but it is a small amount of energy to start motor working. On average a car will draw current strength of about 250 A (voltage 12 V) for 3 seconds to start. That works out to be about 2.5 kWh of energy, or of about 0.2 Ah of electrical charge capacity of a battery. If the battery capacity is 200 Ah, it means losses is 0.1 % of full battery coupled energy (charge). The restore electrical current is 10 times weaker than starter used current and alternator on the car can restore that amount of energy in 30 seconds.

Difficult is using mechanical ignition key to determine moment when starter would finish working exactly. However, new Start/Stop engine systems (engine start or switch button if installed) check it automatically. It is a great innovation.

Alternator is electric power station, also named as generator, produces electric AC current. AC electronically (named rectifier - diodes) converts to DC. When your engine is running, the alternator supplies an electric current for car systems and also fully charges the battery [0.13, 0.16, 0.21]. In modern car computer may control work of alternator. Note: in cars with alternators controlled by more or less advanced computer-controlled communication systems, using a multimeter to measure the voltage may lead to wrong conclusions.

The elements of the electrical and electronic systems are interconnected to functionally unified blocks with copper wires [4.1-4.3]. Car wires are combined in a wiring harness. A wiring harness is an organized set of wires, terminals and connectors that run throughout the entire vehicle. Electric power and information travel through this network.

Today's luxury cars contain some 1500 copper wires - totalling of about 1.6 km in length. For comparison, in 1948, the average family car contained only about 55 wires, amounting to total length of about 46 m. At present the total weight of copper in a vehicle ranges from 15 kg for a small car to 28 kg for a luxury car.

To protect the wiring system are used fuses. A blow fuse may even indicate that there is a faulty device on that line. Most cars (that is not necessarily so) have two fuse panels. The one in the engine compartment holds the fuses for devices like the cooling fans, the anti-lock brake pump and the engine control unit - all of which are located in the engine compartment. Another (interior) fuse panel, usually located in the dashboard near the driver's knees, holds fuses for the devices and switches located in the passenger compartment. When a fuse is blown, it must be replaced before the circuit will work. A blown fuse must be replaced with a fuse of the same amperage. If it is possible firstly more important is to detect why fuse burns out.

All devices, actuators and sensors are connected through individual connectors. Without them, it would be nearly impossible to build or service a car. Connectors help to install or replace devices, actuators or sensors in repair cases. A single connector can have several or a lot number of wires. Car wires (cables) current densities and wiring colour codes can be found in [0.21]. In the past, unreliable connectors have been the source of many electrical problems. Connectors need to be waterproof, corrosion proof and provide good electrical contact for the life of the vehicle. In next paragraphs we shortly debate main electrical systems as battery, starter and then others.

4.2 Battery

The purpose of the battery is to supply the necessary current to the starter motor, the ignition and fuel system while cranking to start the engine. It also supplies additional current when the demand is higher than the alternator can supply and acts as a reservoir of electrical energy.

The engine starting and battery charging systems are interrelated by a continual cycle of converting chemical energy to mechanical energy and then back again. The rotation of the engine drives the alternator, forcing electrical energy (current) into a battery, where it's stored as chemical energy. The chemical energy of the battery is then changed back to electrical energy when it requires. The cycle repeats itself as the engine's mechanical energy again drives the alternator to recharge the battery.

4.2.1 Conventional Battery

The automotive conventional battery, known as a lead-acid storage battery. Lead acid battery technology has been used commercially for over a century. Some archaeological finds of the appropriate materials in a manmade configuration suggest the principle has been known and used much longer time before than that. Their construction is of lead alloy plates, and an electrolyte of Sulphur acid and water (an electrolyte solution, typically made of 35% Sulphur acid (H_2SO_4) and 65% water H_2O). A battery is made up of a number of cells, and the lead acid chemistry dictates a fully charged voltage of about 2.12 volts (V) per cell. Thus, a nominal a 12 V battery has six cells, and a full charge voltage of 12.7 V. High quality, high performance lead acid batteries may exhibit higher cell voltage.

The cell has two plate types, one of lead and another of lead dioxide, both in contact with the sulfuric acid electrolyte liquid. The lead dioxide (PbO_2) plate reacts with the sulfuric acid (H_2SO_4) electrolyte resulting in hydrogen ions and oxygen ions (which make water) and lead sulphate ($PbSO_4$) on the plate. The lead plate reacts with the electrolyte (sulfuric acid) and leaves lead sulphate ($PbSO_4$), and a free electron. Discharge of the battery (allowing electrons to leave the battery) results in the build-up of lead sulphate on the plates and water dilution of the acid.

The reversibility of this reaction gives us the usefulness of a lead acid battery. The sealed versions contain the water, hydrogen, etc. under normal use, to eliminate the maintenance of checking water levels, and corrosion round the terminals.

Charging the battery is reversing the method mentioned above, and involves subjecting the battery to voltages higher than its existing voltage. The higher the voltage, the faster the charge rate, subjecting to some limitations of current density [4.4].

One of the key parameters of battery operation is the specific gravity of the electrolyte. Specific gravity is the ratio of the weight of a solution (sulfuric acid in this case) to the weight of an equal volume of water at a specified temperature. This measurement is usually measured using a hydrometer. The hydrometer is a tool used to measure the specific gravity or relative density of liquids. This is usually the ratio of the density of the liquid to the density of the water. The hydrometer is mainly made of a glass tube with a balloon partly filed with solid material at the bottom. Electronic (digital) instruments currently exist as well. Specific gravity is used as a key indicator of the state of charge of a battery. The Table 4.1 illustrates relation between battery voltage and specific gravity.

Table 4.1. Comparison between battery state of charge, voltage and specific gravity [4.5].

State of charge	Voltage, V	Specific Gravity
100%	12.62	1.265
75%	12.40	1.225
50%	12.18	1.190
25%	11.97	1.155
Discharged	11.76	1.120

An ampere hour (abbreviated Ah, or amp hour) is the amount of energy charge in a battery that will allow one ampere of current to flow for one hour. The mAh provides an indication of how long the PC (personal computer) will operate on its battery without having to recharge it. The battery rating 250 Ah means that the battery can nominally supply 250 A for an hour, or 125 amps for two hours. It means lower current, longer works. In the household we calculate our energy in kWh. If our battery is 250 Ah and voltage 12 V, we may get power P= 250 A×12 V = 3000 W =3 kW or full energy E = 250 Ah×12 V = 3000 Wh = 3 kWh. In comparison, at home we use one or few hundreds kWh per month.

What means the label on battery, for example, 20 HR 66 Ah CCA 620A. HR (Hour Rate) is long time discharge rate (66 Ah/20 HR = 3.3 A). Ah is battery charge capacity in ampere hours (66 Ah). Cold Cranking Amperes (CCA) is a measurement of the discharge current at a high rate that a fully charged battery can deliver for 30 seconds (SAE Standard) and maintain a voltage of 7.2 volts (12 V battery) at a temperature of -18 ^{0}C. The higher the cold cranking amp rating of the battery, the better it is for your car [4.6]. On the battery may be indicated its purpose. For example, battery 12 V for Stop and Start (cars). Conventional lead acid battery is not suitable when Stop and Start system is installed in a car. You need a battery that can be quickly recharged for many times.

4.2.2 Battery for Stop Start systems

The main battery for cars with Stop and Start system is either Absorbed Glass Mat (AGM) or Enhanced Flooded battery (EFB) technology. Both supporting an increased number of charging cycles and increased load. This is important because all the car's electrical system must be maintained by the battery after the alternator stops generating current. Both types are lead acid batteries.

AGM technology became popular in the early 1980s as a sealed lead acid battery for military aircraft or vehicles to reduce weight and improve reliability. The sulfuric acid is absorbed by a very fine fiberglass mat, making the battery spill-proof. This enables shipment without hazardous material restrictions. The plates can be made flat to resemble a standard flooded lead acid pack in a rectangular case; they can also be wound into a cylindrical cell.

AGM has very low internal electrical resistance, therefore it is capable to deliver high currents on demand and offers a relatively long service life, even when deep cycled. AGM batteries provides good electrical reliability and is lighter than the flooded lead acid type battery. AGM batteries are less prone to sulfation and can sit in storage for longer time before a charge becomes necessary. The battery stands up well to low temperatures and has a low self-discharge [4.7].

Enhanced flooded batteries (EFB) are an enhanced version of standard wet-flooded technology. The primary benefits of EFB technology are improved charge acceptance and greater cyclic durability when operating in a reduced state of charge (typical of stop-start applications). For example, shortly we present VARTA EFB Technology for Cars. EFB batteries support applications that operate at a partial state of charge and don't require the deep-cycling characteristics of an AGM battery. A polyfleece scrim material, added to the positive plate surface, makes this possible. This helps to stabilise the active material of the plates, which increases the endurance.

The EFB batteries support a high number off engine starts and extended engine-off periods. Improved is charge acceptance compared to conventional flooded batteries.

Ideal for stop-start vehicle technologies without regenerative braking technology and for vehicles with higher-than-normal energy demands, whether that means a tougher drive schedule or multiple accessories and equipment installed.

In addition, VARTA EFB products are built with Power Frame grid technology for high starting power and reliable performance.

Battery include a unique mixing element inside which reduces acid stratification. It’s a mechanical system that uses vehicle inertial forces to aid the mixing of acid in flooded batteries. The acid density stays at homogenous levels, which enhances charge acceptance and extends the overall battery life [4.8, 4.9].

4.2.3 Battery for Hybrid Electrical Vehicles

Traditional vehicles use gasoline or diesel to power an internal combustion engine. Hybrids use an internal combustion engine like normal cars, but also have an electric motor and battery.

Two types exist of hybrid electrical vehicles, Conventional Hybrid Electric Vehicle (acronyms CHEV or HEV) and Plug-in Hybrid Electrical Vehicle (PHEV). A plug-in hybrid electric vehicle is a hybrid electric vehicle whose battery can be recharged by plugging it into an external source of electric power, as well by its on-board engine and generator. The plug-in hybrid electric vehicle is a hybrid electrical vehicle that can use internal combustion engines, although they're much smaller than a typical hybrid engine and are only used to charge the vehicle's battery when its power is depleted. Conventional hybrids have an electric motor and battery, like plug-ins, but derive all their power from gasoline or diesel and can't be recharged by plugging in. PHEV requires significantly higher battery capacity than CHEV, difference in capacity is about ten times.

The batteries in hybrid cars are responsible for the better fuel economy that's become central to the technology. Hybrid car powers the electric motor, which typically drives a car at some situations. Also, it possible accumulate energy from the braking of the car.

With these new technologies, the demand for batteries is increasing dramatically, creating new environmental challenges. The chemical material that makes up all car batteries, whether it's a conventional car or a hybrid, is typically toxic. Currently, there are far fewer hybrid cars on the road than conventional cars. Therefore, concerns have been raised that if the number of hybrid cars increases, landfills will soon overflow with toxic batteries. Those batteries are full of corrosive and cancirogenic materials. There are three major types of batteries that companies use or are considering for use in hybrid cars: lead-acid (as in Stop-Start case), nickel-metal hydride (NiMH) and lithium-ion (Li-ion). By far, lead-acid is considered the most toxic of the three, and on top of that it's also extremely heavy, reducing some of the fuel efficiency gains from the electric motor. Lead-acid is becoming less of a contender in the hybrid car battery market and is being replaced by nickel-metal hydride. Nickel is less toxic than lead, but it also has some problems, it's potentially carcinogenic and the mining process is considered hazardous. At present many consider lithium-ion batteries to be the next step for hybrid car batteries. In fact, car companies are investing millions of dollars in research for a working of efficient hybrid car battery [1.3, 4.10].

4.2.4 Battery for electric vehicles

Electric vehicles (EVs) only use an electric motor (or few motors) and battery. The battery is recharged at a loading station. Recharging at home is problematic, requires a large power connection. The current two major battery technologies used in EVs are nickel metal hydride (NiMH) and lithium ion (Li-ion, $LiCoO_2$). Nearly all HEVs available in the market today use NiMH batteries because of its mature technology. Due to the potential of obtaining higher specific energy and energy density, the adoption of Li-ion batteries is expected to grow fast in EVs, because of beginning of their use in PHEVs. There are several types of Li-ion batteries based on similar but certainly different chemistry.

Lithium batteries are extremely efficient when made in a certain size. When the batteries are produced in a larger size, they start to heat up. This can cause the battery to overheat and ignite. Also exist problems with ultra-fast charging [1.3, 4.11, 4.12].

The charging size Ampere hours is used to determine the energy capacity of car battery. So, need to say what is the battery voltage. To describe a battery of an electric car in engineering, science or technical literature a more versatile unit is used, which define the energy stored in the battery. However, the tendency is to use a non-systemic unit in kilowatt-hours kWh, which is used for the calculation of the electricity consumed in your home to pay a tax. Now let's show how that looks. Let's say the 80-Ah is accumulated in a traditional lead acid 12.6V battery. The energy of such a battery equals to $E = 80$ Ah×12.6 V and approximately it equal to about 1000 Wh = 1 kWh. It means that the 12.6 V 80 Ah battery accumulates energy of 1 kWh. This simple mnemonic law helps to compare battery installed in hybrid or electric vehicles. If you find that the 20-kWh battery is installed in the vehicle, you'll see it simply that it is equivalent to a twenty conventional examined battery with the above presented parameters. That's why the batteries make up a great part of the car's weight, and also requires add electric motor or few motors that are heavy enough.

In Hybrid electric vehicles (HEVs) there are installed few kWh batteries, in Plug-in hybrid electric vehicles (PHEVs) are installed about 6-16 kWh batteries and in Battery electric vehicles (BEVs) are installed from 16 kWh up to 70 kWh or more. PHEVs can drive distance of about 20 km, BEVs can drive distance of about 100-200 km. Efficiency for PHEVs is about 25-30 kWh/100 km and for BEVs is 20 kWh/100 km. Battery weight can be found from gravity energy density which is about 0.123 kWh/kg (it depends from battery type). For example, for battery of 20 kWh mass of battery equals 163 kg. We will remind you that the battery is expensive and can make up half or third of the car's prices [4.13]. More about batteries can be found in more specialized literature, for example, in references [2.101, 2.102, 4.14].

The battery construction depends on electric vehicle organized power system. If the motor is a DC motor, then it may run on anything from 96 to 192 volts. If it is an AC motor, then it probably is a three-phase AC motor running at 240 volts AC with a 300-volt battery pack [4.15]. For different vehicles can be used and other type of electrical motors [4.16, 4.17]. For instance, electric car battery cells are connected in a 300 V battery pack, the controller (converter) takes in 300 volts DC from the battery pack. It converts it into an effective voltage of 240 volts AC, three-phase, to send to the motor. That is done using very large power transistors that rapidly turn the batteries voltage on and off to create a sine electric current [4.18]. The high voltage is dangerous to human life and strong DC current can operate as electric welding apparatus (welding arc). DC current is more dangerous than AC, it is more difficult to stop DC arc current, requires a greater distance between electrodes. DC current does not alternate through zero point. In particular, the point where current changes direction is when there is zero voltage, and zero voltage means no current is flowing. Since AC current changes direction twice in every cycle. The US and EU use 60 Hz and 50 Hz AC power respectively. So, zero voltage occurs 120 and 100 times every second. This means that arcs in AC circuits are self-extinguishing.

4.3 Starter. Restarting engine

We shortly overview restarting peculiarities in cars with Stop-Start or Idling-Stop System. The same name also may be used for diesel engine cars. We discuss car with petroleum engine. There are essentially three main parts involved in an Idling-Stop system. The engine, an electric starter/generator and a battery. When the car's engine is on and you deaccelerate the car, it may use regenerative braking system (if installed). The rotational energy from the wheels turns the electric generator and creates electricity. The generator sends electricity to the battery where it can be stored for later use. When the driver applies the brakes, however, the system shuts off the engine. Pressing the clutch pedal starts the engine once again by taking the stored energy from the battery and running it through an electric starter, your actions depend on the type of a car gearbox. For more details see manual instructions. This is an important solution, since most fuel economy problems exist from idling and long and frequent stop and go of city driving [4.19].

There is no principal difference between Stop-Start or also called Idling-Stop system and hybrid car systems. In both systems, the vehicle's internal combustion engine is stopped and started. The difference is that in the first case there is no electric motor for driving. For the Stop-Start system, some hybrid car systems can be used. For instance, the Belt-Driven Starter Generator (BSG), the Integrated Crankshaft Starter Generator (ICSG) and other. The Belt Driven Starter Generator system may be another different method to start the engine. The system uses a reversible alternator which also may act as an electric motor. The BSG is integrated into the belt drive system of a traditional combustion engine in the same place as a normal alternator. It has the same fixing points too. The belt is tighter. The system may be used for lower of power engines. The installed starter-generator have two functions in one unit. It replaces both the conventional starter and alternator. That new electric machine is installed directly to the engine crankshaft. It starts engine, helps to accelerate car and may be used to couple energy from regenerative braking. This system is more expensive in comparison with other solutions.

Enhanced starter Stop/Start system consists of a modified starter to meet the requirement of multiple starts as compared to conventional starter. The Engine Stop-Start system in vehicles automatically turns off the engine when the vehicle comes to a stop under certain driving conditions, and can quickly restart the engine in about 0.3 seconds when commanded to do so [4.20]. The modified starter has a high-performance electric motor and a stronger pinion engagement mechanism than a conventional starter. It also has independent control of the pinion and motor.

On a conventional starter, the starter solenoid serves the dual purpose of providing the high-current switch that completes the battery positive current to the DC electric motor and the mechanical solenoid action to push the pinion gear into the flywheel of the engine. The Starter Relay is controlled by the ECM. But on the enhanced starter of a Stop/Start system, these two functions are separated into two different functions inside the solenoid, with each function controlled individually by the ECM. There are two separate relays to control the two separate parts of the enhanced solenoid. They are Starter Motor Relay and Starter Pinion Solenoid Actuator Relay. The two individually-controlled relays allow for smooth engagement of the pinion gear into the flywheel with minimum noise and wear. Computer controls all situations. For a smooth operation of the system, a computer program with prediction estimation is required. More see in Refs. [4.21, 4.22].

The most recent, and perhaps the most significant, example of a vehicle receiving an idling-stop system is the Mazda 3, which will begin using a new and improved type of stop-start technology by the end of 2009. The i-Stop system, Mazda's first start system, detects which piston is in the best position to restart quickest, which is the one in the combustion stroke phase, where air and fuel are in the cylinder, ready to be ignited. The mixture in this cylinder is ignited by the spark plug, forcing that piston down, and with assistance from the starter motor, results in a near instantaneous engine restart time of 0.35 seconds [2.126].

Comparison of the different technologies may find in [4.19]. The complexity is that the effectiveness of these systems is highly dependent on the driving style. The accumulated benefit can be quickly lost by pressing the gas pedal hard.

4.4 Modified alternator and regenerative-breaking

The Stop/Start system's alternator is different from conventional because it is electronically controlled and is adapted to various engine rotation speeds. We present few examples.

BMW has developed the system such that the alternator is not activated most of the time. This means that electrical components in the vehicle are normally running on battery power. When the battery needs to be charged or when decelerating or braking, the alternator is activated to recharge the battery (regenerative braking). Since this battery experiences very different load characteristics than a normal car battery, BMW used an AGM type instead [4.23, 4.24].

Mitsubishi Motors innovative Energy Recovery system [4.25] charges the vehicle batteries when the vehicle decelerates. Mitsubishi Deceleration Energy Recovery system is a technology that charges the vehicle batteries in a concentrated manner using the electrical power generated when the vehicle decelerates, enabling a reduction in electrical power generation in different driving conditions such as idling, acceleration, cruise, etc.

Bosh introduce Efficiency Line alternators [4.26]. Its outstanding performance makes the Efficiency Line alternator ideal for use in Stop-Start systems, as their high output permits rapid charging of the battery. Efficiency Line alternators are particularly efficient at low engine speeds. This means that after every stop the battery is sufficiently re-charged in a very short period of time to permit re-starting without any loss of vehicle power. Denso alternators generates 3 phases alternating current, which offers significant advantages when compared with a single-phase alternating current [4.22].

4.5 Other important electrical system elements

In the car are installed many other important electric components or electrical system elements as, fuel pumps, fuel injection systems, ignition, lighting, indication systems, electric power steering and so on. Below we shortly overview new innovative and interesting ignition system used in petroleum engines. That system is very actual for new cars with an innovative technique such as Stop/Start (Idling-stop).

The different types of ignition systems exist from the older style to fully electronic distributor-less [4.27].

1. Traditional or older style of ignition system. That uses distributor cap with connection points, a distributor, and an external coil. They're high-maintenance, but easily install and quite cheap. Service intervals ranged from every 8 000 km to 16 000 km.

2. An electronic ignition is a modification on the conventional system, and you'll find these in widespread use today. In an electronic system, you still have a distributor, but the points have been replaced with a pickup coil, and there's an electronic ignition control module. These are far less likely to breakdown than conventional systems, and provide very reliable operation. Service intervals on these types of systems are generally recommended every 40 000 km or so.

3. Direct, Distributor-less is the newest type of ignition system and it's beginning to see very widespread use on newer vehicles. It differs greatly from the other two types. In this system, coils sit directly on top of the spark plugs and there is no spark plug wires, so the system is completely electronic. It's controlled by the car's computer. They require very little maintenance, with some automakers specifying about 160 000 km between services. More details, please find in [4.28].

4.6 Electronic systems. Introduction

The development of semiconductor physics is an inessive milestone in human life and economy. The first was to understand semiconductor materials such as Ge, Si, GaAs also, InP properties [4.29]. Parallelly have been exploring possibilities for the use of these materials for practical purposes. Created diodes, transistors were adapted for computer technology. The micrometre-sized and later the nanometre-sized semiconductor elements enable to designed the microprocessors. Finally, they transformed into personal computers, smart phones and, in parallel, were introduced into car control systems. Another important advantage was creating light emitting diodes (LEDs) and lasers (LASER - light amplification by stimulated emission of **r**adiation). Quantum mechanical science was applied to this phenomenon's, and was shown that it is possible to change the properties of a solids crystals by changing the dimensions of the material at atomic level [4.30]. These innovations have brought benefits not only in the science, in the industry, but also in the development of the car control systems, which ensures greater safety, can reduce fuel consumption and lessen the environment pollution.

The growth in the automotive sector is explained by two major trends: one is the extent and pace of change in the industry itself and the other is the significantly higher proportion of electronics that are increasingly used in standard automobiles. Each year, cars seem to get more and more computerized. Cars today might have as many as 50 or more of these microprocessor-controlled devices, known as electronic control units, and some luxury cars have as many as 100 [4.31]. Microprocessors enabled new automotive applications. Ignitions and fuel injection systems became fully electronically controlled, providing lower emissions and greater fuel economy.

Engine control units (ECU) were developed that now include modular transmission control and engine control modules. Up to 50 engine parameters are used, measuring pressure, temperature, flow, engine speed, oxygen level, and NOx levels. ECU outputs connect to up to 30 actuators, for the throttle valve, exhaust gas recirculation (EGR) valve, fuel injector and other systems. ECUs, transmission control and other comprised systems are interconnected and more and more assist to drive a car.

The second results illustrate growth of automotive electronics cost (Year, % of total car cost). The results are seconds: 1980 - 10%), 1990 - 15%, 2000 - 20%, 2010 - 30%, 2020 - 35%? - estimated, 2030 - 50% ?? - estimated [4.32].

Automotive electronics are more specifics and are specially-designed electronics intended for use in automobiles. There are certain requirements for automotive electronics temperature and vibration reliability. For instance, automotive electronics are therefore rated at more extreme temperature ranges than domestic appliances electronics. Most electrical devices are manufactured in several temperature grades with each manufacturer defining its own temperature ratings. The list below is an example of temperature ratings/grades. Note, that the automotive grade is near to the military grade temperature ratings. 1) Commercial 0°C to 85°C; 2) Industrial -40°C to 100°C; 3) Automotive: -40°C to 125°C; 4) Military: -55°C to 125°C. A correspondingly higher price is paid for reliability [4.33].

4.7 Car computer

Each year, cars seem to get more and more sophisticated. Today, cars can have a series of microprocessors. A microprocessor is an electronic device that is the brain of a computer. Its circuit chip contains millions of very small components as transistors, resistors, and diodes. In principle your car is computerized. Because the computerization is very quickly development region there exist some problems with terminology and definitions. In new cars exist an engine control unit (ECU), also commonly called an engine control module (ECM), which is an electronic control unit that controls a series of actuators on an internal combustion engine to ensure optimal engine performance. However, exist definition ECM +TCM = PCM. PCM is Powertrain Control Module. It controls the engine, like the ECU, and the transmission, like a TCM (transmission control module). By placing control of both the transmission and engine into one unit, the PCM can better coordinate their functions for better power delivery and fuel economy. At present **Engine control unit** is more than previously and can exist **as central processor of computer** or simple speaking is car brain or main computer.

Firstly, we present a brief overview of the personal computer (PC). The main components in a typical PC system are the processor, memory, input/output devices, and the communication channels that connect them in one unit. The processor is the workhorse of the system. It is the component that executes a program by performing arithmetic and logical operations on data. Processors can have a single core (individual processing unit) or multiple cores. Similar systems are used in smartphones. Processor is the entire chipset including all the cores in the multicore cases. Cores are like 2 (or more, like 4 core, 6 core or more) parts of the processor that performs parallel processing. Each core itself is a processor technically. But the chipset is manufactured in such a way that the different cores work with coordination and not individually. In relation to computer processors, a core is the processing unit that receives instructions and performs calculations, or actions, based on those instructions. A set of instructions can allow a software program perform a specific function. Processor base frequency of few GHz, for example, 3.6 GHz. The different cores can operate at different frequencies. Computing architecture is 32 bit or at present 64 bit. Computer bus system connects all the internal computer components to the Central Processor Unit (CPU) or simply Processor and main memory.

A bus is a collection of wires through which data is transmitted from one part of a computer to another. A printed circuit board (PCB) is used for connection of computer elements. Wire tracks are chemically etched from one or both sides of cooper laminated on an electrically non-conductive base plate. Only in exceptional cases cables or wires with connections to individual equipment are used.

In PC there are three main types of buses:

1. A data bus can transfer data to and from the memory of a computer, or into or out of the central processing unit.

2. An address bus transfers information about where the data should go. An address bus is measured by the amount of memory a system can retrieve. A system with a 32-bit address bus can address about 4×10^9 bites of memory space. Newer computers using a 64-bit address bus with a supporting operating system can address approximately 1.8×10^{19} bites of memory locations, which is virtually unlimited. But really this number is lower.

3. A control bus is a computer bus that is used by the CPU to communicate with devices that are contained within the computer.

The size of a bus, known as its width, is important because it determines how much data can be transmitted at one time. For example, a 32-bit bus can transmit 32 bits of data, whereas a 64-bit bus can transmit 64 bits of data. Every bus has a clock speed measured in MHz or GHz. A fast bus allows data to be transferred faster, which makes applications run faster.

We remember two terms. The bit is a basic unit of information in information theory, computing and digital communications. It is a smallest unit in binary digit system. Another unit is the byte. It is a unit of digital information that consists of eight (8) bits.

How calculate register memory? A 32-bit register can store 2^{32} different values, it is about 4×10^9 bites. A 64-bit register can hold any of 2^{64} or approximately 1.8×10^{19} bites different values. Also exist other understanding prefixes in binary for bits (bit or letter b) and bytes (letter B) than in decimal system. In decimal kilo k mean 10^3, in binary for bites (bite, b) and bytes (B) that mean 2^{10}; in decimal – mega M mean 10^6, in binary – 2^{20}; in decimal – giga G mean 10^9, in binary – 2^{30}. Example: For binary system 1 Gb = 2^{30} b $\approx1.07\times10^9$ b or 1 GB = 2^{30} B $\approx1.07\times10^9$ B.

In car the computing unit is more complicated system than in simple personal computer. In the car are various computers called electronic control units (ECUs) or control modules. Each ECU has several jobs: controlling the engine or transmission, rolling up windows (not computer but car glass windows!), unlocking doors or other. All system sometimes named as a car computer, however there is no single computer but multiple ones. Sometimes one unit incorporates several of the individual control modules. Some highly engineered cars may contain up to 100 ECUs [4.34].

4.8 Controlling the engine

Controlling the engine is the most processor-intensive job on your car, and the engine control unit (ECU) is the most powerful computer on most cars [4.35]. The ECU collects data from different sensors. The ECU knows everything from the engine coolant temperature to the amount of oxygen in the exhaust. With this data, it performs millions of calculations each second, calculating the results of programmed equations to decide on the best spark timing and determining how long the fuel injector is open. The ECU does all of this to ensure the lowest emissions and best fuel economy.

A modern ECU might contain a 32-bit, 40-MHz processor. This may not sound fast compared to the GHz processor you probably have in your PC, but remember that the processor in your car is running much more efficient codes than that in your PC. The code in an average ECU takes up less than 1 megabyte (MB) of memory. Note, 1 byte = 8 bites. By comparison, if you probably have 2 gigabytes (GB) of programs on your computer, that is 2000 times the amount in an ECU. The electronic system in car is different in comparison with PC. In principle sensors and actuators is connected to microprocessors, which number is from 50 to 100. We have near one hundred small computers. Car electronics is more similar to internet network between individual computers or smart phones.

Failure to fail only affects part of the system. It is also important that the car has so far been designed to duplicate the functions of the car in the main chains. Reliability and additional hedge always require additional expense. Increasing the number of elements always raises the risk of an event. Everyone knows that genius is in simplicity.

4.9 In-Vehicle Networking (IVN) and Protocols

The number of sensors, actuators, comfort elements and navigation systems and their corresponding electronic control units, mostly digital, in the automobile achieved acceleration growing. Digital devices and systems must communicate via an electrical or optical signal employing a well-defined protocol. Protocol is a system of rules that allow two or more entities of a communications system to transmit information. The specific requirements of the different car control units have led to the development of various automotive networks. The signals and protocols constitute a communications bus. Communicating systems use well-defined formats for exchanging various messages. Standardization is a concern of SAE and ISO. SAE (Society of Automotive Engineers) is the International professional association and standard development organization for the engineering industry, with a special focus on the transport sectors such as automotive, aerospace and commercial vehicles. ISO is The International Organization for Standardization, headquartered in Switzerland.

All vehicle electronic wiring network is termed in-vehicle network (IVN). This network or part of them is named Buss System as for PC. There are many Bus or IVN systems used in a car. We discuss only few, more commonly accepted. For more see [4.36-4.38]. At present new vehicles will be made using LIN (Local Interconnect Network) for the lowest data-rate functions, CAN (Controller Area Network) for medium speed, MOST (Media Oriented Systems Transport) for the high-speed data rates and FlexRay (name from Consortium), for safety critical applications such as steer and brake-by-wire. FlexRay can have two independent data channels and operates on a time cycle, divided into two parts static and dynamic. Properties of selected automotive IVN (BUS) systems are presented in Table 4.2. and below table is presented short overview.

Table 4.2. Properties of selected automotive IVN (BUS) systems.

IVN (BUS)	LIN	CAN	FlexRay	MOST
Application	Body: Door locks, windows lift, mirror control, climate control	Powertrain: engine, ABS, transmission	Powertrain: steer-by-wire, stability control	Multimedia: radio, navigation, video displays
Transmission, synchronization	Synchronous	Asynchronous	Synchronous/ Asynchronous	Synchronous/ Asynchronous
Data Rate	20 kb/s	Up to 1 Mb/s	10 Mb/s per channel	24 Mb/s
Wires or Optical Fibre	Single wire, other wire - body	Dual wire	Dual wire (dual channel)	Optical fibre or Dual wire

4.9.1 LIN (Local Interconnect Network)

LIN (Local Interconnect Network) [4.39] is a low-priced serial communication system that was specially developed for cross-linking simple electronic assemblies in automobiles. The LIN bus is a single-wire (other wire is the vehicle body) bidirectional bus typically used for low-speed in-vehicle networks using data rates between 2.4 kb/s and 20 kb/s. LIN is particularly useful in areas where simple sensors and actuators are to be networked as for doors or seats.

4.9.2 CAN (Controller Area Network)

CAN (Controller Area Network) or CAN-bus is an ISO standard computer network protocol and bus standard, designed for microcontrollers and devices to communicate with each other without a host computer [4.40, 4.41]. Development of the CAN-bus started originally in 1983 at Robert Bosch GmbH. The protocol was officially released in 1986. The first CAN controller chips, produced by Intel and Philips, introduced in the market in the year of 1987. The CAN physical layer was realized for use transmission rates up to 1 Mb/s and for use within road vehicles. The CAN BUS line is differential. The wires are a twisted pair (works as cable) with a 120 Ω characteristic impedance. It is not ohmic resistance and you do not measure it with Ohmmeter. You can measure only ohmic loading resistance, if it exists.

The driving voltage (signal) measures or transmits information between that twisted wires. The load impedance of the circuit must be tuned with line impedance to avoid reflections and interference. This is a manufacturer measure problem.

Twisted-pair cable is a type of cabling that is used for telephone communications and now modern Ethernet (ether+net) networks. Ether in physics was a hypothetical theoretical universal substance believed during the 19th century to act as the medium for the transmission of electromagnetic waves (this idea was denied).

4.9.3 FlexRay high speed network

FlexRay is a dual-channel configuration automobile serial data communication technology that is used in very safety-critical use areas. Differential signalling on each pair of wires reduces the effects of external noise does not requires additional shielding.

FlexRay is an automotive network communications protocol developed by the FlexRay Consortium to govern on-board automotive computing. The protocol was introduced in 2000 to develop a standard for high-speed bus systems for distributed control applications in automobiles [4.42]. The FlexRay Consortium Agreement was made up of the following core members:

BMW AG,
DaimlerChrysler AG,
General Motors Corporation,
Robert Bosch GmbH,
Motorola GmbH (become FreeScale),
Philips GmbH (become NXP Semiconductors),
Volkswagen AG.

FlexRay protocol is designed to be faster and more reliable than CAN, but it is also more expensive. FlexRay thus delivers the speed and reliability required for next-generation in-car control systems [4.42, 4.43]. FlexRay has not to date been adopted by mass production vehicle manufacturers and has been more used exclusively by high end premium vehicle.

Dual-channel configuration enhance fault-tolerance and increase bandwidth. Most first-generation FlexRay networks only use one channel to keep wiring costs down. For automotive communication safety requirements, in future networks maybe more widely will be used both channels.

The FlexRay communications bus is a deterministic, fault-tolerant and high-speed bus system. FlexRay delivers the error tolerance and time-determinism performance requirements for x-by-wire applications. It may be used in drive-by-wire, steer-by-wire, brake-by-wire, etc.

The CAN network has reached its performance limits with a maximum speed of 1 Mb/s. FlexRay with a maximum data rate of 10 Mb/s per channel, available on two channels, giving a gross data rate of up to 20 Mb/sec. FlexRay communication has 20 times higher net bandwidth than CAN network when used in the same application.

4.9.4 MOST bus

MOST (Media Oriented Systems Transport) is a high-speed multimedia network technology optimized by the automotive industry. That is serial communication system for transmitting audio, video and control data mostly via fibre-optic cables. The serial MOST bus uses a daisychain topology or ring topology and synchronous data communication to transport signals. System requires professional software tools and hardware interfaces.

The MOST Cooperation is the organization through which the technology is standardized and is in line with the latest technology [4.44]. The MOST Cooperation was founded in 1998 to standardize MOST Technology as a global standard for multimedia networking. Audi, Daimler, Harman and Microchip Technology as core partners form its Steering Committee.

MOST now provides distributed network protocols for multimedia high-definition (HD) audio/video networking. MOST also supports Digital Transmission Content Protection (DTCP). DTCP is a digital rights management technology.

MOST management includes not only physical connection between devices but also provides the software infrastructure to control the multiple devices communicating with each other. For example, telephones, navigation systems or other portable media devices. It all maybe integrated in the car.

Via MOST bus connection of audio, video, and necessary control signals over a single cable maybe realised, using either optical fibre or unshielded twisted-pair (UTP) wires. At present known MOST Standards MOST25, MOST 50, MOST150, where numbers are operation rate in Mb/s [4.45, 4.46]. For more professional information see in Refs. [4.47, 4.48].

4.10 Car communication ports and their functions

We define which car communication port is an interface or a point connection between the car electronic system and peripheral devices. Devices can be connected via removable cable or wireless radio frequency (RF) technology. Some of the common peripheral devices are Tire pressure sensors, RF Entry Key, Car diagnostic and programming device, also cellular phone or other multimedia. In Table 4.3 are presented car communication ports and their functions.

Table 4.3. Car communication ports and their functions.

Port	Bluetooth	RF	USB	OBD
Frequency/Pins	2.4 GHz	315 MHz (USA) 434 MHz (EU) 125 kHz	4 pins	16 pins
Applications	Multimedia, mobile phone	Keyless entry system, TPMS, Immobilizer, Passive Keyless Entry	Memory device, multimedia, mobile phone	Car diagnostics, programming

Bluetooth is a wireless electromagnetic waves of 2.4 GHz frequency technology standard for exchanging data over short distances (5-30 m) between fixed and mobile devices. For computers Bluetooth also uses 5 GHz Technology. Internet RF communication uses 2.4 and 5 GHz WiFi Technology. Bluetooth is technology that allows two compatible devices to communicate. A Bluetooth port enables connections for Bluetooth-enabled devices for synchronizing. Typically, there are two types of ports: incoming and outgoing. The incoming port enables the device to receive connections from Bluetooth devices while the outgoing port makes connections to Bluetooth devices. In the car, it lets you to operate a mobile phone hands-free, meaning you don't have to hold the device while making or taking a call or performing such functions as accessing the phone's address book.

Radio frequency (RF) remote keyless system (RKS) also called remote keyless entry (RKE) or remote central locking, contain a short-range radio transmitter, and must be within a certain range of the car to work. Most RKEs operate at a frequency of 315 MHz for North America-made cars and at about 434 MHz for European cars.

Passive keyless entry (PKE) is an automotive security system that operates automatically when the user is in proximity to the vehicle about 0.7 m, unlocking the door on approach or when the door handle is pulled and locking it when the user walks away or touches the car on exit. Similarly, Immobilizer is RF very short-range security system and activates only when controller is inside the car body. That systems operates at approximately 125 kHz frequencies, similarly as Near field communication NFC system in smart phones, which operates at 13.56 MHz frequency. About Passive keyless entry system and Immobilizer, and about its peculiarities we discuss later in next chapter.

A tire-pressure monitoring system (TPMS) is an electronic system designed to monitor the air pressure inside the pneumatic tires. It is named Direct TPMS, because also exist Indirect. As tire pressure data is collected for each tire, it is sent to one or more TPMS receivers, using RF technology. The majority of Direct TPMS installations transmit their data via RF signal. TPMS data is typically transmitted at about 434 MHz in Europe, and at 315 MHz in North America.

USB (Universal Serial Bus) inputs are digital connections designed to connect and charge a wide range of devices. USB ports in cars may be used for some applications. Charge your media devices (when used in conjunction with appropriate cables). Play music files from a USB flash memory. Connect and play audio from selected media devices such as smartphone, player. Different cars support different functionality via USB ports. Some USB ports will only charge devices, meanwhile others will fully integrate your smartphone. If exist Bluetooth, normally you can use both in tandem, so you can play music via USB but make and answer phone calls hands-free via Bluetooth.

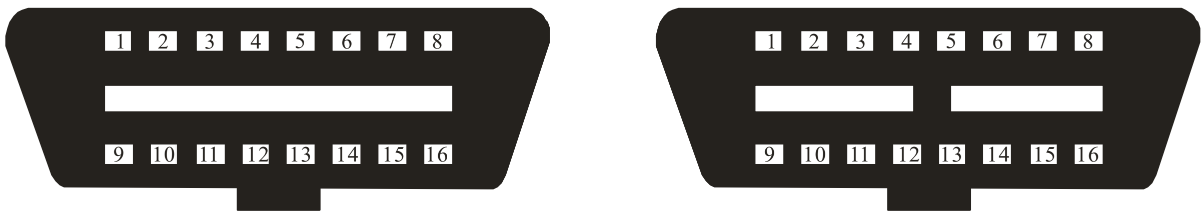
The three previous discussed ports are not intended for computer programming of the car or transfer of data to a car computer. The motor and other equipment of the car cannot be affected by it. In the car mostly important port is On-Board Diagnostics (OBD). It requires more explanations.

4.11 On-Board Diagnostics (OBD)

On-Board Diagnostics (OBD) is an automotive term referring to a vehicle's capability of self-diagnostic and reporting. OBD systems give the vehicle owner or repair technician access to the status of the various vehicle subsystems. On-Board Diagnostics was the name given to the early emission control and engine-management systems introduced in cars. There is no single OBD standard. Each manufacturer often using quite different OBD systems. OBD systems have been developed and enhanced, in line with United States government requirements. That regulates the current OBD II standard. All cars and light trucks built and sold in the United States after January 1, 1996 were required to be OBD II equipped.

EOBD is the European equivalent of the American OBD II standard, which applies to petrol cars sold in Europe from 2001 and diesel cars from 2003. For simplicity we use term OBD or OBD-2, if necessary, use EOBD or EOBD-2 as well.

At present all cars have a standard OBD diagnostic socket that provides access to this system [0.13, 4.49-4.51]. In all cars installed the OBD 16-pin diagnostic connector DLC (Data Link Connector), or in more cases named as OBD connector. Exist two types of the connectors, A and B. The type A connector is used for vehicles that use 12V supply voltage, whereas type B is used for 24V vehicles. That's shown in Fig. 4.1. The data link connector is the multi-pin diagnostic connection port for automobiles, trucks, and motorcycles used to interface a scan tool with the control modules of a given vehicle and access on-board diagnostics and live data streams. The standardized diagnosis interface is located in the vehicle interior and must be accessible from the driver's seat. Information on the pins used within the OBD port are presented in Fig. 4.1 and Table 4.4.



Type A female connector   Type B female connector

Fig. 4.1. The OBD connectors type A and type B. The type A connector is used for vehicles that use 12V supply voltage, whereas type B is used for 24V vehicles.

Table 4.4. Information on the pins used within the OBD port. ISO is The International Organization for Standardization. SAE is The Society of Automotive Engineers.

Pin	Standard (Protocol)/Use	Signal	Pin	Standard (Protocol)/Use	Signal
1	*		9	*	
2	SAE J1850 Bus + Voltage 5V	Variable pulse width (PWM), 41.6 kb/s	10	SAE J1850 Bus	PWM Max voltage 5V
3	*		11	*	
4	Chassis Ground		12	*	
5	Signal Ground		13	*	
6	CAN High (ISO 15765-4) Voltage 3.5 V	250 or 500 kb/s	14	CAN Low (ISO 15765-4) Voltage 1.5 V	1Mb/s Differential voltage 2 V
7	ISO 9141-2 K-Line	Asynchronous, 10.4 kb/s	15	ISO 9141-2 L-Line	Asynchronous, 10.4 kb/s, Max voltage 12V
8	*		16	Battery Power (+)	
* - Not used for OBD. These pins are not standard and are vendor specific. It is also not required for normal communication/interfacing.					

The SAE (Society of Automotive Engineering) standard on OBD-II J1962 defines the physical connector used for the OBD-II interface. J1939 defines a data protocol for heavy duty commercial vehicles. The SAE J1962 specification provides for two standardized hardware interfaces, called type A and type B. Both are female, 16-pin, D-shaped connectors. Both connectors have a groove between the two rows of pins, but type B groove is interrupted in the middle. This prevents the insertion of a type A male plug into a type B female socket while allowing a type B male plug to be inserted into a type A female socket.

The technical implementation of EOBD is essentially the same as OBD-II, with the same SAE J1962 diagnostic link connector and signal protocols being used. Therefore, an OBD2 system diagnoses the car's engine and checks if everything's working correctly. If it's not then there is a display of a trouble code, as in a Check Engine light error. This light doesn't go away until the problem is fixed and helps the driver know that something is not right with the system.

The SAE J1850 bus is used for diagnostics and data sharing applications in vehicles. The J1850 bus takes two forms: a 41.6 kb/s Pulse Width Modulated (PWM) two wire differential approach, or a 10.4 kb/s Variable Pulse Width (VPW) single wire approach [4.52].

ISO 15765-4 (CAN-Bus) is the most modern protocol and communication is differential. Four variants of ISO15765 exist. They differ in bus speed. This protocol has been mandated in all vehicles sold in the US from 2008 and later. However, if you have a European car from 2003 or later, the vehicle may have CAN. It's a two-wire communication method and can run at up to 1Mb/s [4.53].

ISO 9141-2 protocol is for a Chrysler, European, or Asian vehicle. It runs at 10.4 kb/s and is asynchronous serial communication [4.54].

4.12 On-Board Diagnostics and parameters identification

On-Board Diagnostics (OBD) [0.16, 0.22, 4.54, 4.55] is a computer-based system built into all 1996 and later light-duty vehicles and trucks. It was designed to help control emissions and engine failures. The first information is presented as the Check Engine warning light on the dashboard is often the first from which an owner knows about a problem with their car. This provides very little information to the owner, or to the garage master asking to investigate the problem.

Light on dashboard also sometimes popularly named as "idiot light". "Idiot light" is a coloured light on an instrument panel designed to give a warning, for example, that in engine is low oil pressure. The "idiot light" terminology arises from automakers. Previously were used gauge instruments which measurers pressure, voltage, temperature. It was possible detect changes in parameters and prevent or solve problem. That operation is not possible via an "idiot light", which lights only when a fault has already existed and not detail information what to do. The Hudson automobile company was the first to use lights instead of gauges for oil pressure and the voltmeter, starting in the mid-1930 [4.56].

At present with the modern tools, which are expensive, connected to OBD connector, skilled technicians are able to diagnose and solve many of the car electronic and sensors problems. The on-board diagnostics standards have opened up new opportunities for car garages and owners. A range of low-cost tools are now available to read and clear error codes, to view live/stored readings from sensors within the car, and to switch off the Check Engine light. OBD systems monitor and store information from sensors throughout the car. New diagnostic tools can help you read and interpret these codes, and view the live sensor output. There are also installed or updated ECU (car computer) programs via OBD connection. In other words, OBD is the language of the Engine Control Unit (ECU), and it was designed to help to fight emissions and engine failures.

We shortly debate about reading performance Information Data (PID) or in other words OBD Parameter Identifications Data (PID). PID are codes to request data from a vehicle, used as a diagnostic tool. PIDs codes provide valuable diagnostic information when checking the operation or status of various sensors, circuits and switches in the vehicle's engine management system. Scan tools can read PID codes. Different scan tools have different capabilities to display PID codes. The Original Equipment Manufacturer (OEM) scan tools used by new car dealers are capable of displaying every possible PID value that is built into the engine management system.

Most general-purpose aftermarket scan tools do not contain the software that allows them to match the Original equipment manufacturer scan tools in every respect - but for most applications they can display all the important PID codes. Code readers and scan tools will also display Stored Diagnostic Trouble Codes (DTC). Also exist other Pending Trouble Codes. These are codes that indicate a fault has been detected, but that the fault has not yet repeated. If the fault repeats under similar driving conditions, it will usually cause the Pending Code to become a Stored Code and turn on the MIL (malfunction indicator lamp) light. A Check Engine light or malfunction indicator lamp indicates a malfunction. It requires to solve problem. If problem solved lamp switch off automatically. If you have fixed the problem, but the light persists, you will need a scan tool like an OBD reader, or consult with the master. Diagnostic Trouble Codes or OBD2 Trouble (or Fault) Codes are codes that the car's OBD system uses to notify you of an issue. Each code corresponds to a fault detected in the car. A vehicle stores the trouble code in its memory when it detects a component or system that is not operating within acceptable limits [4.57].

There exist two types of **trouble codes: Generic and manufacturer specific** codes. A trouble code is an alphanumeric value that corresponds to a particular type of fault. The list was originally created by the Society of Automotive Engineers (SAE) for use by all vehicle manufacturers who have to comply with OBD II emissions regulations in the U.S. The same list of basic codes has also been adopted by European and Asian auto makers. The list of trouble codes is subdivided into four basic categories: Powertrain "P" 00 (zero zero) codes (engine, transmission and emissions systems). Body "B" 10 (one zero) codes (climate control system, lighting, airbags, etc.). Chassis "C" 01 (zero one) codes (antilock brake system, electronic suspension and steering systems). Network Communications "U" 11 (one one) codes (controller area network wiring bus and modules). Note: Binary numbers in brackets are explained.

The first number in the DTC indicates whether the code is an ISO/SAE generic code (applies to all OBD-II systems) or is specific to the vehicle manufacturer. The remaining three numbers provide information regarding the specific vehicle system and circuit.

The definition for the code is defined in the EOBD/OBD-II standard and will be the same for all manufacturers. Manufacturer-specific, where manufacturers feel that a code is not available within the generic list, they can add their own codes. The definitions for these are set by the manufacturer. In general, codes that begin with P0 are Generic codes, whereas codes that begin with P1 are manufacturer-specific. Structure of generic and manufacturer trouble codes is presented in Table 4.5.

Table 4.5. Generic and manufacturer-specific trouble codes structure.

<table>
<tr><td colspan="5">EXAMPLE</td></tr>
<tr><td>P</td><td>0</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>Letter</td><td>Type of code</td><td>(P0) Subsystem code</td><td colspan="2">Fault description, explanation
P 0 2 02</td></tr>
<tr><td>Trouble code subsystem</td><td>Generic (ISO or SAE) / Manufacturer</td><td rowspan="5">1 - Fuel, Air
2 - Fuel system
3 - Ignition
4 - Exhaust
5 - Idle control
6 - I/O ECU
7,8,9 - Gearbox, Transmission</td><td colspan="2" rowspan="5">P - Powertrain
0 - Generic
2 - Fuel system
02 - Injector for cylinder 02 (two)
Generic code P0202 indicates that the ECM has detected a malfunction for the cylinder 2 injector circuit. The code is set once the Engine Control Module (ECM) detects out-of-range voltage or resistance.
It is possible failing or failed cylinder 2 fuel injector. Poor or broken electrical connection</td></tr>
<tr><td>P-Powertrain</td><td>0, 2 / 1</td></tr>
<tr><td>B-Body</td><td>0, 3 / 1,2</td></tr>
<tr><td>C-Chassis</td><td>0, 3 / 1,2</td></tr>
<tr><td>U-Network</td><td>0, 3 / 1, 2</td></tr>
<tr><td colspan="5">More see below.</td></tr>
</table>

The 5-digit code means.
1st digit:

P = Powertrain (engine, transmission/gearbox);
B = Body (air conditioning and airbag);
C = Chassis (ABS);
U = Network code.

2nd number:

0 = Generic fault codes common in most vehicles;
1 = Brand specific fault code.

3rd number.

Indicates the subsystem the code:
1 - for fuel and air metering;
2 - for fuel and air metering (injector circuit);
3 - for the ignition system or misfire;
4 - for auxiliary emission controls;
5 - for vehicle speed control and idle control system;
6 - for the computer output circuit;
7, 8, 9 - for transmission (gearbox);
A, B, C - for hybrid propulsion;

4th and 5th number.

0-99 - Indicates the specific area of the subsystem that triggered the fault.

Please remember that now trouble codes only refer to a specific circuit. Replacing the sensor or actuator without confirming that it is really fail with other methods may not solve the problem. That may be an unsuccessful idea. It would be more logical, first unplug it and check with multimeter (multitester). More information about trouble codes and also tables of codes may be found in internet [4.58-4.60]. Best training is to open tables of trouble codes. You may view your car diagnostic codes.

4.13 Diagnostic and erasing trouble codes

The car fault code means the system has detected a problem in one of the onboard systems and sends a message. Faults can come from any electronic system or sensor in your car. However, there are thousands of possibilities and all of them are converted into a simple 5-character fault code. The best and safest way to detect and erase trouble codes is to use a scan tool. The tool communicates with the vehicle computer and tells it to erase the codes. It does not affect for normal vehicle operation. Cleaning the codes, it does not mean that the Check Engine light is off. Sooner or later, the codes will be resettled and the Check Engine light will be back on. After diagnose a problem, it requires to repair a car first of all. Knowledge of more detailed fault report allows you to decide whether a failure is essential and you have to stop the car and call for help or you can calmly go to a garage or service to fix the malfunction.

4.13.1 Understanding diagnostic trouble codes

Diagnostic trouble codes (or fault codes) are codes that are stored by the on-board computer diagnostic system. These DTC's identify a particular problem area and are intended to provide the technician with a guide where a fault might be occurring within the vehicle.

Codes should be used in conjunction with the vehicle's service manual to discover a problem. Parts or components should not be replaced with reference to only a DTC. The vehicle service manual should be consulted for more information on possible causes of the fault, along with required testing. For example, if a DTC reports a sensor fault, replacement of the sensor is unlikely to resolve the underlying problem. In this situation could help simple tester, for example, to find a bad contact or fault sensor.

Increasing the complexity of modern cars increases the needs for modern diagnostics, maintenance and repair technique. Modern cars can be repaired only by qualified specialists with good diagnostic skills and tools. The vehicle continues to be more complex and the need for specialists of higher quality is increased. Insertion of computers between owner and car leads to sophisticated situations. Already in the car there are entire light emitting fault diagnostic lights and a corresponding message. However, it is not always known how to proceed with the receipt of a message. There exist small number of clear messages, for example, finished windows washing liquid. In principle, it is worth to invest in a diagnostic tool in order to make a qualified decision what to do. This is like a spare wheel, which also needs investment. The question is what level a diagnostic device to buy and how much it will cost. No doubt, this will require for the car owner and additional knowledge.

You can pull out the OBD-II codes from your vehicle in various ways. Most auto parts stores will offer a device that plugs into a computer port. Also, you could get a scanner tool [4.61]. If you insert an unknown tool, you'll do it at your own risk. Now cheap or universal type code readers are only getting to be ready to do things that are exposed as OBD-II parameters. For ABS, airbag or more generally SRS (Supplemental Restraint System) requires special readers. Some readers may need the proper protocols and should be ready to read the airbag codes, but even then, they could not be able to clear the code for technical or liability reasons. Airbag, SRS and ABS systems normally require other special tools that are out of reach for many do-it-yourself (DIY). They're critically important and delicate systems. Erasing the error code isn't the solution. The car will repeat the message that the problem isn't resolved.

Not having the right diagnostic tool won't just waste some time trying to find the faults, but you'll need to clear these codes somehow after repairs. Having the right diagnostic tool will allow you to be employed effectively. Investing in diagnostic equipment will improve your business and vehicle repair ability and speed. These tools are not only an expensive material, but may be a necessary investment to grow knowledge and accurately exploit the modern vehicles.

4.13.2 OBD-II scan tools

There are hundreds of OBD-II scan tools or code readers on the market. They cost from near hundred to few thousands Eur. If you are not properly instructed, or your understanding is inadequate, you could purchase a scanner that reads only a small amount of your vehicle's available information.

Some OBD scanners come preloaded with definitions for OBD-II codes, but otherwise you'll need to have a list like that which can be found on OBD-Codes.com. However, in addition to the generic codes that apply to all cars, individual manufacturers have their own specific codes. Finding these codes can be problematic, as not every manufacturer is entirely comfortable with the idea of releasing them to the public. Thus, working with a good scanner means less hassle and difficulty.

Fig. 4.2. Professional scan tools Autel MS 906 BT and Launch MOT II (new MOT III). They are both connected by Bluetooth. More details see Table 4.6. Adapted from [4.62].

The best cars diagnostic instruments are professional scan tools. Professional scan tools are of two basic types: original equipment manufacturer (OEM) dealership specific and generic aftermarket. Factory or manufacturer-specific scan tools are only available to new car dealerships for exclusive use on specific makes of vehicles they sell and service. Dealership scanners have all the latest, greatest information available directly from OEMs about the vehicles they manufacture. Factory scan tools also allow professional technicians to perform many more diagnostic tests on specific system components. OEM scanners can also be used to reprogram a vehicle's, for example, power-train control module (PCM) with the latest factory software updates.

The OBD-II scanners can be divided in two categories:

1. The OBD-II scan tools, which are the more expensive type, and which include info about manufacturer specific codes.

2. The OBD-II code readers, also named as scanners, which can read and clear codes. Also, more expansive can show and advanced data. Can include bidirectional functions.

The OBD-II scanners can be divided by format connection:

1. Bluetooth scanners which operates wirelessly without cable connections. For this purpose, can be used smart phone, Tablet, Laptop or Personal computer.

2. WiFi scanners which operates wirelessly without cable connections. They are similar to Bluetooth, but operation distance is few times longer, and signal transfer speed may be higher.

3. PC based scanners uses cable connection, most USB. Requires Adapter or interface to convert OBD-II signal to USB signal. They are able to diagnose and troubleshoot issues for your car. Possibilities depends on adapter (interface) and software. Part of OBD-II adapters are manufacturing for Bluetooth, WiFi or USB connections (that does not realize physically in the same adapter).

4. Hand-held tools and scanners are mostly popular, used by professional mechanics. They may be connected to OBD-II connector through cable, but at present mostly through Bluetooth Connector. An additional WiFi communication system is also installed in this instrument. They may automatically update tool through internet. It can get help and support. They are able to detect brakes, transmission system, the engine and other as comfort problems of the car. They are the powerful OBD diagnostic tools.

Original Equipment Manufacturer (OEM) and various level Generic aftermarket OBD2 diagnostic systems with the manufacturer's names are presented in Table 4.6.

Table 4.6. Original equipment manufacturer and Generic aftermarket OBD2 diagnostic systems. Information gathered from the manufacturers or the manufacturer's official representatives [4.62-4.68].

No.	Professional diagnostic tools, Originals		Approx. cost
1.	Original equipment manufacturer (OEM)	Uses in certified services. Detect and erase trouble codes. More diagnostic tests on manufacturer specific system components. OEM scanners can also use to reprogram a vehicle with the latest factory software updates	Very expensive. For authorized services. The biggest part of the price is the price of the software
Professional diagnostic tools, Generic aftermarket			
2.	CU serial programming tool via onboard OBDII (Cable)	Diagnostic, programming and Chip tuning. Auto, Moto, Agro. Alientech KESS v2	About 10 000 Eur with all software
3.	Diagnostic tool Highest functionality BT/cable	Full OBD 2 diagnostics for high number of cars. Ecu coding. Pass through programming. Launch X-431 Euro Tab II Autel MaxiSys Elite Include J2534 programming module	About 4 000 Eur, Paid updates
4.	Diagnostic tool Medium functionality, BT	Full OBD 2 diagnostics for medium number of cars. Ecu coding. Launch X-431 Euro Pro4 Autel MS906 BT	About 2 000 Eur, Paid updates
5.	Code reader with expanded functions, bidirectional, BT/Cable	Full OBD 2 diagnostics for medium number of cars. Service light reset, TPMS reset, Injector programming and other. Launch Creader Profess. MOT II, III Autel MaxiCheck MX808 (Cable)	About 700-850, 600-700 Eur, Paid updates
Professional/Do-It-Yourself (DIY) type (Generic aftermarket)			
6.	Code reader/eraser with expanded functions, Cable	OBD 2 diagnostic for several selected cars. Service light reset, SRS, ABS, Launch CRP 129 Premium Autel MD 802 Maxidiag Elite	About up to 300 Eur, Internet updatable
Do-It-Yourself (DIY) type, Generic aftermarket			
7.	Code reader/eraser, Cable	OBD 2 diagnostic for several selected cars. Read codes/Clear codes. Launch CRP S1 Autel Autolink AL329	Up to 100 Eur, Internet updatable
Note: BT means Bluetooth system, uses vehicle interface diagnostic connector (VCI) to transfer signal from OBD connector to Display-Tablet computer wirelessly without cable.			

Modern OBD2 diagnostic systems include WiFi connection for internet and online updating. Also, may be installed USB port for connection with PC.

Highest functionality diagnostic tools include Pass through or also named flash programming. It requires special connector, sometimes named as J2534 or simple J-box. SAE J2534 is a concept that enables flash programming of an emission related ECU regardless of the communication protocol that is used by the ECU. The purpose is that only one tool (hardware device), often also referred to as the pass-thru device, should be needed for all kind of ECUs.

Chip tuning is changing or modifying an erasable programmable read only memory chip in an automobile's or other vehicle's electronic control unit (ECU) to achieve superior performance, whether it be more power, cleaner emissions, or better fuel efficiency. Some companies also offer performance upgrades for specific vehicles that remap or alter software to unlock horsepower. Modern vehicles are dependent on computer controls. Software changes can affect air intake or exhaust system. It’s worth noting that nonprofessional upgrades may have negative effects in the reliability or fuel economy and should also void the factory warranty. Chip tuning has some risks and dangerous. It is not for garage makers [4.69].

4.13.3 Cheap OBD-II scan tools

We shortly overview a few cheap and easy to use Car OBD2 diagnostic systems, see Table 4.7.

Your smart phone may be converted in OBD Diagnostic tool. In principle smart phone is the same instrument as PC or tablet computer.

At present many OBD diagnostic tools are working with Android operation system. Your Android or IOS smart phone can be successfully converted into diagnostic tool. There are a number of OBD-II-related mobile applications. Searching Google Play or Apple’s iTunes, you’ll find over few hundreds smartphone applications that essentially turn a smartphone into a scan tool. We will present few OBD-II apps. However, having an OBD-II app on a phone doesn’t allow to do any good unless there is a way to connect the phone to an automobile’s OBD-II system. Typing in OBD-II smartphone adapter into Google’s search engine proposes hundreds of adapters. The adapters connect via an USB cable, Wi-Fi, or Bluetooth. Connection with the Bluetooth interface being the most popular. We present one of the possible adapters.

The ELM 327 is a programmed microcontroller produced by ELM Electronics [4.70, 4.71]. The ELM 327 command protocol is one of the most popular PC-to-OBD interface standards. The problem raised because ELM Electronics did not enable the copy protection feature of the microcontroller. Consequently, anyone could buy a genuine ELM327, and read ELM's proprietary binary microcontroller software using a device programmer. With this software, pirates could trivially produce ELM327 clones by purchasing the same microcontroller chips and programming them with the copied code. The problems begin with copied production.

Table 4.7. A few cheap and easy to use Car OBD2 diagnostic systems.

No.	Diagnostic Adapters		Approx. cost
1.	Most popular ELM 327 (Elm Electronics)	Connection: Bluetooth, WiFi, USB (It is only possible connections)	Genuine 20 - 40 Eur
2.	OBD Link (Scantool)	Bluetooth, WiFi, USB	50 -100 Dol
3.	BlueDriver	Bluetooth (works with its app)	150 Dol
4.	Kiwi (PLX Devices)	Bluetooth	50 - 150 Dol
No.	Diagnostic Software		Approx. cost
1.	Torque Lite	Smart Phone: Android	Free
2.	Most popular: Torque Pro	Smart Phone: Android	Cheap
3.	OBD Auto Doctor	Pc, Smart Phone: Android	Paid
4.	OBD Car Doctor	Smart Phone: Android, IOS	Free

ELM 327 type scan tools, see Fig 4.3., represent an affordable alternative to basic car code readers. These devices use ELM 327 technology to interface with your vehicle's OBD-II system, but they don't have any built-in software, display, or anything else that a traditional code reader has.

Fig. 4.3. Photo ELM 327 type scan tools.

ELM 327 type scan tools are designed only to provide an interface between a tablet, smartphone, see Fig. 4.4, laptop, other PC and your car's computer through OBD connector. Basic free application programs allow you to use an ELM327 scan tool on your smart phone, more advanced software often provides you with a more powerful interface and diagnostic information.

Most cheap or universal type code readers are only going to be able to do things that are exposed as OBDII parameters and do not read OEM codes. For example, air bags are not a part of the OBDII specification, and thus requires a special reader. Some readers might have the right protocols and may be able to read the airbag codes, but even then, they might not be able to clear.

Fig. 4. 4. Torque Pro and OBD Auto Doctor [4.72, 4.73] installed programs first page view on Android Galaxy phone.

4.13.4 The risk of using OBD-II scan tools

Modern cars are getting more and more advanced and hard to diagnose. Modern cars use self-control units. If there's not a parameter that's correct, it leads to a trouble code. With a DTC tool, we will get that trouble code and begin to find defect or plan to travel into auto service. The question is whether or not you generally need such a tool. Here it's up to you. Purchasing such a tool will raise your qualification to a higher level and increase your understanding of the modern car. It's just an enormous investment in knowledge and your education as concern the vehicles. It actually seems that even choosing an OBD-II scanner isn't easy. We'll mention that. There are a lot of different things to understand before once you plan to buy an OBD2 scanner.

1. Need

Before you decide to buy a diagnostic scanner, you should find out what diagnostic results you would like to get from your car. You ought to know whether you would like to have the diagnostic scanner only for diagnostics or for repair also. Each scanner features a specific and different purpose. If you're a car technician or work in a garage you would possibly need a diagnostic scanner that's compatible with a wider range of vehicles. If you employ personally, you'll use a more specific scanner for family cars.

2. Compatibility

Different OBD2 scanners are compatible with varying models of car. The foremost Generic trouble code scanners can read the most vehicles after 1996. If you want to read other control units like Airbag, ABS, and transmission or others, you need the scanner which is compatible with your vehicle. Many car manufacturers have specific manufacturer trouble codes that you only can read with good OBD2 scanners.

3. Functionality

You have to ask yourself which functions you would like in the scanner. If you are getting to do any coding (after changing repair parts) or other basic settings, you'll need to choose a costlier OBD-II scanner. If you're only getting to read the trouble codes of the engine control modules and nothing more, then of about twice cheaper generic trouble code scanner would suit to you better. Below you'll understand that for a cheaper scanner is cheaper to upload programs. If you would like to read other control units and manufacturer trouble codes, you've got to think about buying a costlier scanner which is compatible with your car model and engine. You can buy scanner with added diagnostic functions as TPMS reset, Injector programming, Steering angle sensor reset or other useful functions for little workshops.

4. Bidirectional ability

A bidirectional scan tool may be a device that you simply use to send commands to a control module and receive feedback. The simplest automotive scanner tool is the one that's capable of programming the vehicles electronic module and other on-board modules. These scanners are very expensive. However, there are cheaper scanners with added diagnostic functions and with some abilities of programming, for instance, programming injectors.

5. Price

The price is a crucial part once you decide to buy a scanner. But it's not a main part. The cheaper scanner can also be very useful essentially for beginners. If you've got a workshop and are reading several cars each day, you'll want to urge a more durable and more professional scanner, which can probably cost more. Better is to buy a generic scanner from a known company. You'll work with very expensive electronics of the car. The worth of the device depends on the number of features of the device and therefore the capabilities of the scanner. If scanners show a full report and outline of the matter, these scanners are usually costlier.

6. Software updates

One of the foremost important issues is updating the appliance of the device. That is often important to understand before buying a tool. There are different options. Buying a tool usually comes with a one-year or two-year warranty on free updates. Then, updates are purchased. What matters now's what happens if you don't continue with the updates. Some companies' devices stop working without the software being not updated. The scanners of other companies are operating without ordering any longer updates. They normally work, but without updates and new information. There are also free updates (life free update scanners) for cheaper scanners. You need to understand updates aren't cheap. The costlier scanner, the costlier updates. The value of the updates per annum could also be up to at least one third of the worth of the scanner you're purchasing.

7. Warranty

Always check the warranty time of the scanner before you buy it. A lot of diagnostic scanners come with a one or two-year warranty. This ensures that you are simply going to be on the safe side if you encounter a problem within the device. It's always better to shop for a scanner that gives a guaranty. Also, better to buy a scanner which will receive complete upgrades and has the supply of accessories in your area.

8. Modern options

As the technology is getting advanced, so it is a sweet idea to buy a cable-less scanner with a Bluetooth connection. It's better that you simply buy a scanner that has WiFi. That connection enables you to attach the scanner to the Internet and easily to get Online One click internet update. It's possible send Email too. It's also recommended that you simply get a diagnostic scanner that's simple and straightforward to use. Better scanner is which includes codes explanation and help. It's better to urge a scanner with an optimal display size and with touch screen. This enables you to control the scanner and read the diagnostic results easily. You'll work like a smartphone. Some scanners have one or two cameras installed.

9. Warning

It is not dangerous to use an OBD-II scan tool if the tool is certified. Now known company’s scanner tools on the market are safe. Could also be problem once you are working and automobile battery discharges. You'll registry many mistake codes. Problems are often resolved with connection charger to automobile battery. Don't drive with connected OBD tool and don't leave it within the car connected. There are devices that will draw a large amount of power even when your car is at rest or device is in a sleep mode. If you're driving and the car is in diagnostic mode, it might be dangerous. Reading the knowledge or trying to update codes may interfere with the traditional operation of the vehicle. The simplest way is to urge instructions or recommendations from dealers. Leaving the OBD-II code reader (or interface adapter) that has Bluetooth or WiFi (or both) installed switched on within the car will make it easier for thieves to unlock or steal the car.

10. Additional motivation

There are many reasons to shop for an OBD-II scanner. The one among the foremost important is that you simply will economize within the while. Every visit to the mechanic, even for a touch of detail, will cost you a dose. You furthermore may spend time calling for service and getting to an auto service with an unknown problem. So, with the OBD-II scanner, you'll check your car's internal health. It'll make it easier for you to debate your car's problems with a mechanic. The discussions are going to be more skilled. The buying an honest OBD-II scanner may be a perfect investment that every modern car owner should do. Then you won't need to take your car to the mechanic whenever after the message Check Engine.

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Chapter 5 Safety, Security & Comfort

The driver has got to answer himself a few of the questions before traveling. Are you driving a car safely? Another would be to make sure your car is safe and works well technically. You must cherish your property and take care of its protection. Today, the manufacturers take care of it quite well. No less important detail is the comfort of the car. It creates a comfortable environment for travellers, makes it easier to drive and reduce fatigue.

The travel depends on the road conditions. The mass excess road signs, as well as road or street advertising that doesn't really increase traffic safety. If the vehicle is overloaded with the media and the information systems does not contribute to increasing travel safety. Everything must be what is necessary.

How to buy a safe vehicle? Firstly, it should have its crashworthiness body and secondly, the advanced safety systems. If your vehicle is safe, keep in mind that safety also depends on how you maintain and drive your vehicle.

5.1 Car Safety introduction

Since the first car rolled off the assembly line, the regulation of automobile safety systems laws has changed drastically. Modern automobile safety regulation laws begin in the late 1960s. Car safety systems start from seat belt laws, also vehicle crashworthiness tests, and more recently the regulation of air bags. The United States has developed some of the world's may be bests and strongest automobile safety standards [5.1].

Vehicle safety in European Union countries is regulated mainly by an international standard and regulation devised by the European Union (EU) and the United Nations Economic Commission for Europe (UN ECE). In recent years the mostly important vehicle safety Directives deals with crash tests for frontal impact protection and side impact protection to car occupants and also tests for pedestrian protection.

The vehicle was modified to provide protection against injury in the event of a crash for those inside and outside the vehicle. For more important is new technologies that are emerging which may help the vehicle to play its part in crash prevention. Some technologies such as electronic stability control, intelligent speed adaptation emerged.

Much work is being carried out on advanced technologies such as collision avoidance systems. In European roads the effectiveness is not yet clear determined.

For the short to medium term, therefore, preventing or reducing death and serious injury in the event of a crash continues to be the major role for vehicle safety improvements. The World Report on Road Traffic Injury Prevention informs about crash prevention systems [5.2]. Crash factors may be associated with roadway geometrics, way conditions, etc. Also, human factors, like car driver, another car driver, pedestrian, motorcyclist behaviour. Also, important are vehicle factors which contribute to crash avoidance and survivability. Environmental conditions like snow, ice, rain, and wind require adequate driving. Analysis generally show human factors are a big component of altogether crashes, but other factors, like roadway factors, are influenced also.

Engineers examine all crash factors to work out how human behaviour and attributes are often suffering from signage, roadway design, etc., to scale back crash risk.

Here are presented several samples of human factors in accidents. First of all, the aggressive driving and alcohol. Occupant protection - drivers and passengers who choose not to use safety restraints are at a higher risk for injury and death. Driver inattention - distracted drivers don't give enough attention to the driving task. Distractions include factors both inside and outside of the vehicle. Drivers' attention may be distracted by advertising on roads or streets. The driver all time must check road signs and that the traffic rules have not been violated. Inside the vehicle, drivers are likely involved to multitask, e.g., talking or text messaging on cell phones, conversing with passengers, eating meals or snacks, changing the station or CD, shaving or putting on make-up, reading maps, etc. [5.3].

In 2013, 96% of each new car sold within the US came with an event data recorder (EDR), and as of Sept. 1, 2014, every new vehicle must have one installed. Event Data Recorders are electronic devices, commonly called Black Boxes. If you're buying a car from a dealership, they need to inform you if the car features a recorder.

Black boxes record some information. the knowledge includes vehicle speed, throttle position, airbag deployment times, whether the brakes were applied, if seatbelts were worn, engine speed, steering angles and more. Manufacturers can also have up to 30 additional data points if they need to, excluding, they say, GPS location, video and audio. Also, a recorder only stores information for 20 seconds round the crash. Raises the questions of who can access the information within the first place and safety of recorded data and personal security of the owner [5.4, 5.5].

The European Parliament introduce eCall regulation which requires all new cars to be equipped with eCall technology from 31 March 2018 [5.6]. In the event of a serious accident, eCall automatically dials 112 - Europe's single emergency number.

It communicates the vehicle's exact location to emergency services, the time of incident and the direction of travel, even if the driver is unconscious or unable to make a phone call. An eCall can also be triggered manually by pushing a button in the car, for example, by a witness of a serious accident. Information only leaves the car in the event of a severe accident and is not stored any longer than necessary.

112 eCall is not a Black Box. It does not record constantly the position of the vehicle. It records only a few data to determine the position and direction of the vehicle just before the crash and these data are only transmitted to emergency call centres if there is a serious crash.

eCall cannot be used to monitor motorist's moves. The SIM-card used to transmit the eCall data is dormant, i.e. it is only activated in case the vehicle has a serious accident (e.g. the airbag is activated).

112 eCall is not expensive. The cost is estimated to less than € 100 per car at the date of entry into force of the proposed regulation. This cost is expected to decrease in the future, following the trends of electronic components' costs and also due to economy of scale. Ultimately all new cars will be equipped with 112 eCall in the EU and in some neighbouring countries [5.7].

The connection to information systems in today's cars provide many benefits. They include using GPS navigation to get to a destination, pairing a phone to an audio system to play downloaded music or to easily answer calls and so on. Equipment used in a car is expensive and needs to be stored. For instance, don't leave a portable GPS unit or any other electronic device in your car, better take it with you. Lock your glove box if that's where you keep your insurance and registration information. Protect not only the car documents but also personal documents. More you can find in reference [5.8].

5.2 Safety systems

Car safety systems, which include a wide range of features, are divided into two classes: Passive safety systems and Active safety systems. The systems are different and it is useful to discuss each system separately [0.28].

Passive safety systems are automobile safety systems that are only deployed or being effective in response to an automobile crash. These systems protect drivers and passengers from injury once a collision occurs. Passive systems include seat belts, air bags, seats for children, crashworthiness body.

The air bag, a passive system which is now mandatory in every new automobile sold in the USA (also EU), works in conjunction with the seat belt to provide two levels of safety in the event of a crash. Although current NHTSA (National Highway Traffic Safety Administration) regulations require air bags only for front passengers, many advocates are pushing for the installation of advanced air bags to protect all passengers. Advanced air bags include smart air bags and front and rear side curtain air bags that provide greater protection than regular air bags for all passengers in the event of an accident. Passive safety systems are very reliable systems.

An active safety system works or helps to prevent an accident. These systems function behind the driver influences. Computer systems monitoring the driving conditions and actively adjusting the driving dynamics of the vehicle to minimize the risk of an accident.

The Antilock Braking System (ABS) is one type of Active system. The ABS is superior to regular braking in preventing wheels from locking up. On slippery surfaces, the ABS provide better control than a regular braking system and may yield shorter stopping distances. Electronic Stability Control (ESC) is an Active system that is increasingly found in a greater number of vehicles. The ESC system is based on the premise that a computer-controlled system can effectively monitor driving conditions and vehicle course. If there is any deviation, the ESC system automatically intervenes by applying brakes and cutting engine power as needed to bring the vehicle back to its intended course [5.1]. In Table 5.1 and Table 5.2 are presented passive and active safety systems, respectively.

Table 5.1. Passive safety systems.

No.	Name	Comment
1.	Front Airbags	It is restraining device designed to inflate rapidly during an automobile collision. It prevents the driver and passenger from striking the steering wheel or a window
2.	Curtain Airbags	In case of side collision, occupants in both rows are protected by curtain airbags extending along the sides
3.	Seatbelt Front 3-Point	A most commonly used seatbelt in cars today. 3-point seat belts are belts that goes over the waist (lap) and the shoulder (sash) of the occupant. Front Seatbelts are equipped with Pretensioners (seatbelt pre-tension mechanism), Force Limiters and are height adjustable
4.	Seatbelt Rear 3-Point	A most commonly used seatbelt in cars today. 3-point seat belts are belts that goes over the waist (lap) and the shoulder (sash) of the occupant. Rear Outers Seatbelts are equipped with Pretensioners and Force Limiters
5.	Headrests (Head restraints)	When positioned properly, the headrest stops the backward movement of the head in a rear end collision
6.	Collapsing steering column	Once a specific level of pressure is exceeded, the special resin shatters, allowing the sleeves to compress column telescopically
7.	Safety cage, part of the body	It works together with the crumple zones to protect the occupants of a vehicle in the event of an accident
8.	Safety glass	The windshield glass in your car is made of laminated glass, which is designed to offer highest levels of safety in the event of a crash
9.	Lights	Informs other drivers about your actions and takes a look at the dark at night
10.	Mirrors	Proper alignment of mirrors ensures high visibility and eliminates the blind spots
11.	Child Safety Seat	Designed specifically to protect children during vehicle collision
12.	Child Lock in a car	It means a lock rear door that can’t be opened from inside

Table 5.2. Active safety systems.

No.	Acronym	Name	Comment
1.	ABS	Antilock Braking System	ABS only operate under heavy braking or on slippery surfaces
2.	EBD	Electronic Brake Distribution	Automatically varies the amount of braking force applied to each of a wheel for max advantage
3.	EBA/PBA	Brake Assist System	Applies brake pressure to allow the driver to take max advantage
4.	ESC	Electronic Stability Control	ESC becomes active when a driver loses control of their car
5.	TC	Traction Control	Optimize grip and stability of the car
6.	PAEB	Pedestrian Auto Emergency Braking	To prevent a crash or reduce the impact speed of a crash
7.	AEB	Auto Emergency Braking	Warning plus the ability to brake. Reduce the risk of nose-to-tail and pedestrian-based accidents
8.	ACC	Adaptive Cruise Control/Active Cruise Control	Slows down and speeds up automatically to keep pace with the car in front, requires radar. Supports car in traffic flow
9.	HDC	Hill Descent Control	It allows a controlled hill descent in rough terrain without any brake input from the driver
10.	HSA	Hill Start Assist	Prevents vehicles rolling backwards (about 2 seconds) and makes hill starts easier
11.	LKA	Line Keep Assist	When the car reaches the lane marking, the car nudges itself away from the marker

Traditionally step-by-step in cars was introduced various warning, alert and other auxiliary safety systems, which are presented in Table 5.3. Warning information is not much actual and does not require fast execution. Alarm is very actual information and requires to act appropriately.

At present is introduced definition Advanced driver assistance systems (ADAS) which include systems to help the driver in the driving process. When designed with a safe human-machine interface, they should increase car safety and more generally road safety.

There is no unanimous opinion in the literature about what modern car systems to include in ADAS list. Some include active and alert safety systems. Others emphasize that driver-assist systems use cameras and sensors to watch out for hazards.

At present it is required the high resolutions automotive radar sensors. For this resolution signal bandwidths in the gigahertz range is used. For this reason, radio frequency electromagnetic wave bands from 24 GHz (wavelength 1.25 cm) up to 79 GHz (wavelength 3.8 mm) are provided for these applications. Sensors operation distance may be up to 250 m. Sometimes may be used laser system named as LIDAR, which stands for Light Detection and Ranging. It is very similar to the RF Radar. A laser pulse is sent out of a laser and the light particles (photons)/electromagnetic waves are reflected back to the receiver (photodetector). You can measure distance to object and its speed. For instance, Lidar specifications: Max average power 45 mW, pulse duration 33 ns, wavelength 905 nm (infrared). Radar uses radio waves to detect objects and determine their position, angle, velocity. Lidar does basically the same things, but with pulsed laser light rather than continuous radio waves. It is two different technologies that achieve the same goals. Note: RF and light are both electromagnetic waves but different wavelength and are different generation and registration technology.

Table 5.3. Warning, alert and auxiliary safety systems.

No.	Acronym	Name	Comment
1.	TPMS	Tire Pressure Monitoring System	TPMS alerts drivers when tire pressure is above or below the required pressure
2.	FCW FCM CAS	Forward collision warning Forward collision mitigation Collision avoidance system	Also known as a pre-crash system, forward collision warning system, etc. They are a safety system to prevent or reduce a collision with car or pedestrian. Radar (sometimes laser, LIDAR) based, automatically applies the brakes
3	BSW LCA	Blind spot warning Lane change assist	Detects other vehicles located to the driver's side and rear. Monitor the perimeter of the car Use cameras, radar, and/or ultrasonic sensors
4.	LDW	Lane Departure Warning	This feature beeps and displays a warning if the vehicle drifts from its lane, while the turn signals are not operating. Camera-based system
5.	UPA	Parking sensors (Front/Rear) Ultrasonic parking assist	Parking sensors (ultrasonic) will alert the driver with an intermittent or continuous buzzer sound when the vehicle approaches an object and the sensor detects that object during parking
6.	RVC	Rear-view camera	Rear-view camera, screen activate when the driver puts the car in reverse
7.	SVS	Surround View System	Surround vision (bird- or fish-vision system). The bird's eye view provides the 360-degree, top-down view. This system normally includes between four and six fish-eye cameras mounted around the car to provide right, left, front and rear views of the car's surroundings
8.	TSR	Traffic Sign Recognition	Detects and reads road signs. Warns when it detects speed limit signs, stop signs
9.	SWS	Speed Warning System	The speed warning function will warn you if the vehicle exceeds the pre-set maximum speed
10.	RCTA	Rear cross-traffic alert	Radar sensors monitor both sides. Helps to prevent backing into cross traffic by providing alerts when vehicles are detected
11.	T	Temperature $T \leq 3^0$ C	External Warns drivers possible ice on road
12.	WFL	The windscreen washer fluid level	Warns when the windscreen washer fluid reservoir is almost empty

Driver-assist systems provide audible or visual and sometimes physical alerts if they sense a potentially dangerous situation, and some can even take action such as applying the brakes to avoid a collision or steering a car back into its lane. For more information find in [5.9, 5.10].

5.3 Security systems

In our century many of us begin to argue that car alarms are not any longer effective. Automobile insurance companies and enforcement agencies have both completed studies that reveal car alarms don't noticeably reduce car theft. Exist information that car alarms are increasing crime, instead of reducing it, thanks to the growing number of call outs in reference to complaints about faulty alarms. The rationale is that car alarms are so sensitive that they're usually triggered accidentally, with the result that folks became resistant to them, ignoring them as false alarms. Car alarms are somewhat effective against amateur thieves.

As a result, car manufacturers are introducing stronger mechanical protection systems and improved electronic security systems. It's an incontrovertible fact that the event of car computerization may be a perfect match for car thieves. There are new opportunities to electronically break in cars. In this paragraph, we'll present how modern security systems work. We will try to contribute to the safety of your expensive assets in ways. For instance, 40-50% of auto theft is due to driver error, which incorporates leaving vehicle doors unlocked and leaving keys within the ignition or on the seats [5.11, 5.12].

Standard installed in car security systems are presented in Table 5.4. One of the oldest simple, but effective security is Steering Wheel Lock. Passenger automobile regulations implemented by the U.S. Department of Transportation required the locking of steering wheel rotation or transmission locked in park position to hinder motor vehicle theft, when the ignition key is removed from the ignition lock [5.13].

Modern vehicles are fitted with the steering lock which is an anti-theft device. System is fitted to the steering column usually below the steering wheel. The lock is combined with the ignition switch. Ignition key also locks or unlocks steering wheel. When in car is installed remote keyless entry system this is done electronically.

Table 5.4. Standard installed in car security systems.

No.	Acronym	Name	Comment
1.	ESCL	Steering Wheel Lock Electronic steering column lock	It is an anti-theft device and fitted to the steering column. The lock is combined with the ignition switch and engaged, and disengaged either by a mechanical ignition key or electronically
2.	VIM	Immobilizer Vehicle Immobilizer	Near field communication NFC electronic coded signal security device allowing start engine
3.	RKE	Remote Keyless Entry System	Radio frequency (RF) electronic coded signal entry device
4.	PKE	Passive Keyless Entry	Near field communication NFC electronic coded signal device allowing open/close doors or tailgate

An engine immobilizer is an electronic security device which the modern cars use. The engine immobilizer is an anti-theft system built in the engine ECU. It prevents the engine from starting without using vehicle's authorized key.

This system uses a special digitally coded key or a Smart Key fob. This key contains a transponder chip. It stores the electronic security code or simply the vehicle's password. The ECU does not activate the fuel system and the ignition circuit if the code in the key & that stored in the immobilizer does not match.

When the driver inserts this digital key into the ignition switch or takes the Smart Key fob inside the vehicle, the key transmits the electronic code to the Engine Management System of the vehicle. The engine can start only if the code in the transponder chip inside the key or Smart Key fob matches with the code in the engine immobilizer.

The immobilizer function can be performed by the simplest secret switch that blocks the start of the ignition system, starter or electric fuel pump.

The immobilizer is Near field communication NFC electronic device similar to NFC port in Smart Phones. Difference is the operation radio waves frequency. For smart phones operation frequency is more higher 13.56 MHz (operation distance <20 cm), for car immobilizers works in the region of 125 kHz frequency. The physical operation principle is different than TV or Radio in which main role plays electric field. NFC devices operates using induction magnetic field. Electromagnetic field consists of two components, electric and magnetic. Communication may be organized using one component, for example, magnetic. In this case receiver and antenna are combined by two wired coils separated in space. It works as electric transformer. The principal schema of immobilizer is shown in Fig. 5.1.

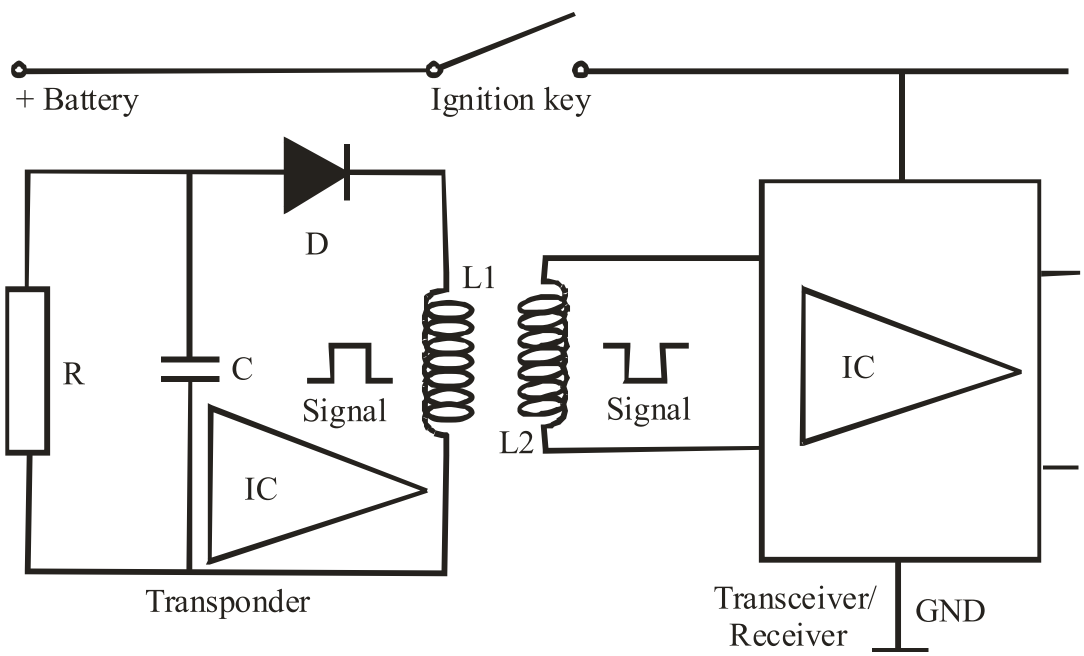


Fig. 5.1. The principal schema of immobilizer which does not require battery (self-powered). L1 and L2 inductive coupling coil antenna. R is resistor, C is capacitor and D is diode to convert part of AC signal to DC, which is supply for IC (integrated circuit). Adapted from [5.14].

The transponder inside the key or in keyless entry remote is powered by inductive coupling so that no batteries are necessary. The operating distance is very small, several tens of centimetres. In order to increase the operating distance, it is necessary to increase the power of the devices, for example, transponder can be connected to an electric battery [5.14].

An advanced electronic Engine Immobilizer system in latest cars uses rolling/changing security codes. This system featuring in BMW cars which consists of two steps security. A first personal code and a changing second code. Each time the key starts the engine, the system changes the second code and stores it in the key. Whenever the driver switches on the ignition, the immobilizer first reads the personal code. Then, it requests for the second rolling code. After both these codes are verified, only then the immobilizer sends another coded signal to the engine control system to unlock the engine. Without this, the engine does not start. In the absence of the second security code, still, the engine will not start. Short-circuiting of the ignition system does not help to start [5.15].

Remote Keyless Entry (RKE) system contains a short-range radio transmitter, and must be within a certain range, usually of about 10 up to 100 meters, of the car to work. You can easily measure the distance from the start of the keyless fob. The name fob does not mean how system works, about it will be presented below. When a button on fob is pushed, it sends a coded signal by radio waves to a receiver unit in the car, which locks or unlocks the door. Most RKEs operate at a frequency of 315 MHz for North America-made cars and at about 434 MHz for European cars. The functions of a remote keyless entry system are contained on a key fob or built into the ignition key handle itself. Previously alarm activation/deactivation panel or electronic locking system was fob to main keys. At present it is completed in one unit and named as fob. For this name exist various explanations. One of them. The word fob is believed to have originated from watch fobs, which existed as early as 1888. The fob refers to an ornament attached to a pocket-watch chain. Key chains, remote car starters, garage door openers, and keyless entry devices on hotel room doors are also called fobs, or key fobs [5.16].

The hopping or rolling codes used in modern remote-entry systems are extremely sophisticated. A rolling code transmitter is useful in a security system for providing secure encrypted radio frequency transmission comprising an interleaved trinary bit fixed code and rolling code. A receiver demodulates the encrypted RF transmission and recovers the fixed code and rolling code. Upon comparison of the fixed and rolling codes with stored codes (at present included random number generators) and determining that the signal has emanated from an authorized transmitter, a signal is generated to actuate an electric motor or solenoid to open or close a movable component such as doors. At present there is a one-in-a-billion chance of your transmitter opening another car's doors. When you take into account the fact that all car manufacturers use different systems and that the newest systems use more and more bits, you can see that it is nearly impossible for any given key fob to open any other car door.

You can also see that code capturing will not work with a rolling code. With a rolling code, capturing the transmission is useless. There is no way to predict which random number the transmitter and receiver have chosen to use as the next code, so re-transmitting the captured code has no effect. With trillions of possibilities, there is also no way to scan through all the codes because it would take years to do that. However, as with most forms of technology, the software can be bypassed. In recent years, thieves have manipulated weaknesses in the technology, so that vehicles can be stolen without the key [5.17]. This will be presented in the next paragraph.

Passive Keyless Entry (PKE) and Start Systems in Modern Cars with Smart Key systems on all modern automobiles work in similar ways. The car uses a low frequency radio-frequency

125 kHz identification (RFID) tag that provides short range communication (one to two meters in active mode, and just a few centimetres in passive mode, to allow the key and the car to communicate, verify that the key is the right one for that car, and allow the car to start. In principle PKE works on the same principle as immobilizer. It is NFC system. The PKE can be used as immobilizer if does not installed another transducer chip.

For more security may be designed system to use simultaneously both PKE and RKE systems [5.18, 5.19].

5.4 Breaking into Your car and prevention

All drivers and car consumers have much interest in car security problems. Please more read in [5.20-5.22]. We present only short overview of that problems. We will point out what you can do yourself to avoid mistakes. People in particular suffer from negligence or simple neglect. Modern cars are well enough protected by car manufacturers against theft. Without regard to this, the owner needs to protect and cherish his property.

5.4.1 Signal jamming

Signal jamming is the most common way thieves gain access to a car. It blocks attempts to lock your vehicle. Jamming technology enables easy access to a vehicle without any physical damage. For this purpose, the device transmitting more power noise signal on the same radio frequency as remote key fobs works is used. Thus, it is possible that your car has been left unlocked. This method is used to steal items inside the car. But it can be used to access the OBD connector. Therefore, when you click on the lock button, watch flash, or mirrors is rotated, or hear the sound of the locked door. If you are not guaranty, you can manually check if the door is locked.

Never leave valuables in a visible place inside the cabin. Especially avoid leaving documents.

5.4.2 Relay attacks

Pressing button on a car door or touching the handle if installed capacity sensor Passive Keyless system emits a short-range radio signal that travels about one meter. When the correct key fob is close by, the fob recognizes the signal and transmits its own code, instructing the vehicle to unlock the doors. The same process is used for the ignition on cars with start buttons. Note, PKE fob transmitter is not switched off. That is made for the convenience. It is not the need to take a key fob in hand.

A relay attack usually involves two people working together. One stands by the targeted vehicle, while the other stands near the owner with a device that can pick up a signal from the key fob.

You can block electronic key fob signals using a Faraday-style wallet or metallic box for screening electromagnetic waves. For NFC system it is important magnetic component of electromagnetic waves. It is better use magnetic material as steel (iron), stainless steel is not suitable. Also, in this case the copper or aluminium are not effective materials.

5.4.3 OBD attacks

This method consists of few steps. Initially, thieves get into the car by breaking the window or using jamming technique. Then they attach a sophisticated reader (computer) to the on-board diagnostics connector. This allows them to read information about your car, including the unique car key code. They can disable your vehicle immobilizer, de-activate the alarm, code new keys and then drive away! All of this can be done in less than few minutes. Most OBD ports are located inside a car in the front footwell. As a rule, the data accessible by the OBD connector has to be openly available, meaning the vehicle manufacturer can't encrypt the information.

Possible prevention, fit a lock to your OBD port and use additional security such as a steering-wheel lock.

One of the recommendations, don't leave unlocked a car with running engine. Second, may be better, don't leave your car with running engine.

Don't keep spare keys in your car. Do you think you've got a great hiding spot for your spare keys? Car thieves know surely where to look.

The biggest mistake you could make is leaving the window open. Few centimetres can be just what it takes for a car thief to easily steal your car.

Before installing additional protection systems that are particularly expensive, make sure that they are so effective. For instance, a GPS tracking system. People may be able to install a GPS tracking system, however, their vehicle can be stolen too. Offenders can use simple a signal jamming device and you will not realize that your car is stolen and is going to another location.

5.5 Comfort systems

Comfort is a very widely used word. We don't even think what it means. There exist different explanations of this word. It so happens that comfort has a very broad meaning. Here we present one of them. Physical comfort is the feeling of well-being brought about by internal and environmental conditions that are experienced as agreeable and associated with contentment and satisfaction [5.23].

The car various comfort systems are presented in Table 5.5. Basic question about comfort. Is it the first necessity for the car? It is clear, comfort improves the safety of the car, increases the mood of the driver and passengers, improves well-being [0.28]. Nowadays, the car with new communication possibilities, is not only a vehicle, but it can also be a communicative workplace. It can become as a Staff Office on wheels. Keeping in mind the fast development of the cars at present, the cars in future may be left without a driver. Who knows...?

Table 5.5. Car comfort systems.

No.	Name	Comment
1.	(Keyless) Start/Stop Engine	Requires the key fob in car. Push button. Requires additionally push clutch or brake pedal. Without pedal you can switch only OFF, ACC (Accessory) or ON
2.	Multi-information (function) Display, Multifunction Instrument Display MFID	Displays warnings, information: the odometer, trip odometer, engine coolant temperature, fuel remaining, outside temperature, selector lever position, average and instant fuel consumption, driving range, average speed, etc. Tachometer and Speedometer
3.	Cruise Control (Constant speed)	The car at a constant speed and RPM is very good for the engine. Do not use your cruise control on winding roads, in heavy traffic or slippery roads
4.	Adjustable steering wheel	Adjust steering wheel manually or electrically (if equipped). Do not adjust while driving
5.	Auto-Dimming mirrors	Inside, outside (if equipped) auto-dimming. Operation Electrochromic principle, dyes (material) change reflection light intensity in an electric field. Also, requires two light sensors (front and back) to obtain optimal electric field
6.	Automatic lights switch	Many higher end cars have automatic headlights and tail lights. They switch when is dusk or dark. Also, may be installed automatic Daytime Running Lamps
7.	Automatic High Beam	Switch automatically to low beams and automatically switch back
8.	Navigation System	For example, Global positioning system (GPS). Navigation system is your travel with guide. Also, it may be used for other controls of car
9.	Automatic control of wipers	A rain sensor mounted onto windshield from the inside car. It sends out infrared light. When water droplets are on the windshield, reflected back light intensity changes, detector sense it and switch on wipers
10.	Adjustable front seats	Adjust seats manually or electrically (if equipped)
11.	Seat heaters	Adjustable electrical heaters: Front, Rear (if equipped)
12.	Automatic air conditioning/ Automatic climate control	Dual zone
13.	Premium audio/radio system	Surround audio system, subwoofer, sound amplifier. Remote controls on steering wheel
14.	Bluetooth	Smart phone. Audio Media
	Handsfree Phone	Remote controls on steering wheel. Voice control function
15.	Display Audio (without or with) Smartphone Link	Touch Screen. Online images from webcams
16.	Multimedia System Display	Touch Screen or a scroll wheel and touchpad fitted to the centre console. It can be used to control a range of

		the car's functions from sat nav to multimedia features
17.	Head-up Display HUD	Its projects drive and multimedia related information onto (or near) a translucent film on the windscreen. Controls: Touchpad Controller
18.	USB	Audio Media, flash memory audio. Smart phone (if installed): Android Auto, Apple CarPlay

5.6 A rear-view system

A rear-views mirrors in automobiles and other vehicles, are designed to allow the driver to see rear view. Inside in cars, the rear-view mirror is usually affixed to the top of the windshield allowing it to be adjusted. The problem arises at night when another car at the end of your car can lighting mirror and can blind you. Respectively you can to adjust the mirror by using the switch at the bottom of the rear-view mirror.

5.6.1 Reducing glare

Inside rear-view mirror glass isn't flat - it's a wedge of glass that's thicker on one end than the other. With flip switch you can adjust the mirror between day and night positions. In the day view position, the front surface is tilted and the reflective back side gives a strong reflection. When the mirror is moved to the night view position, its reflecting rear surface is tilted out of line with the driver's view. Only a much-reduced amount of light is reflected into the driver's eyes.

The problem with a standard rear-view mirror, of course, is that, while it can be reduced glare by being flipped up the mirror and providing a reflection behind you, this has the effect of dimming of everything substantially.

An auto-dimming mirror dims automatically when there's a bright light behind you, it also dims in proportion to the light source it's dealing with, meaning the dimming effect will be far less pronounced when there's a relatively faint light in your mirror. This feature has also been incorporated into side-view mirrors allowing them to dim and reduce glare as well, but not in all cases.

In the automotive industry, the technology used for the creation of dimming mirrors is called electrochromism and the resulting glass electrochromic. Electrochromism is the phenomenon where the color or opacity of a material changes when a voltage is applied. For instance, transition metal oxides such as WO_3, TiO_2, Cu_2O etc., have been investigated as electrochromic materials [5.24]. In order for the dimming mirror to be effective, something must tell it when it's time to act. Dimming mirrors used in the automotive industry are fitted with sensors to detect the intensity of the light. Usually, there are two photo sensors, one pointed to the front and therefore the other to the rear. The inside mirror's sensors and electronics may control the dimming of both interior and exterior (if equipped) mirrors.

The sensors, when active, are constantly looking for low ambient light. Poor lighting messages the sensors you are driving at night and they begin looking for a glare source which may impair your vision. When they detect a change in light intensity, they trigger an electrical field to be applied to the glass through a low-voltage power supply. The electricity travels through an electrochromic gel in between the two electrically conductive coated pieces of glass which darkness the mirror. As a result, the mirror darkens proportionally to the light signals detected by the sensors. When the glare is no longer detected, they go to their calm state [5.25, 5.26].

5.6.2 Adjusting the outer mirror position

Outer Rear-View Mirror (ORVM) is mirror, through which driver can see vehicles behind/ near back of car while driving. Internally adjustable ORVM means there can be a manual switch/handle near the window by which the mirror position can be adjusted. That doing without moving hands outside and physically adjusting. Whereas in the electrically operated one there are motor actuators and switches. They help in adjusting the viewing angle. The electrical control mirrors offer more convenience. You may adjust both mirrors. Do not attempt to adjust the rear-view mirrors while driving. This can be dangerous. Always adjust the mirrors before driving. The outside rear-view mirrors can be operated when the ignition switch or the operation mode is in ON or ACC.

Heated mirrors on vehicles keep themselves free from fog and ice the same way the defroster keeps the windshield clear. A small amount of heat is applied to the glass surface of the side mirrors. Electrical elements in the mirrors heat the surface of the glass. The heater will be turned off automatically in about 20 minutes (may be other time, see your car manual).

5.6.3 The rearview mirror/camera

For instance, Nissan has developed a rearview mirror with a built-in LCD monitor displaying images from a camera mounted on the rear of the vehicle [5.27]. This Intelligent Rearview Mirror allows the driver to have the ability to switch between the LCD monitor and the standard rear-view mirror, depending on the driver's preference. The driver is able to see traffic conditions behind the car through the clear video imagery, as well as use the rear-view mirror to check on passengers in the rear. This helps make for a safer and more comfortable driving experience.

The Intelligent Rear-View Mirror (I-RVM) gives the driver the option of switching modes to turn the vehicle’s rear-view mirror into an intelligent camera giving a look-around view of the area behind the vehicle. The effect is accomplished by the presence of a rear-mounted camera connected to an LCD monitor built into the rear-view mirror.

The Intelligent Rear-View Mirror is a convenience feature but it is not a substitute for properly installed traditional vehicle mirrors. The system also has areas where objects cannot be viewed. It requires to check the blind spot of the Intelligent Rear-View Mirror before vehicle operation. The driver is always responsible for safe driving.

5.7 Car lights

A car’s various lights have specific functions either to help the driver or to signal to other drivers. When used improperly, or not in the least, accidents can happen. Neglecting that at the present more functions of lighting controls automatically car computer, however it's important to be ready to know the various lamps and when to use them. There are up to fifteen or 17 external lights within the car. There are 2 custom headlights, 6 indicators that's 2 front, 2 rear, 2 either side. Even have 2 front fog lights, 1 or 2 rear fog lights, 3 break lights and therefore the last 1 or 2 reverse lights. Short description finds in [5.28, 5.29].

Vehicle manufacturers pay special attention to the looks of the car. A crucial element is car lights. Also, there's a crucial design of taillights. Innovative technologies, good lighting and style got to be combined too. Lately, light is seen as a design element of the car.

5.7.1 Headlights

There are two types of headlights - low beam and high beam. These lights allow the driver to see the roadway in the dark, and also signalling to other drivers that a car is present. Low beams provide a light distribution to give adequate forward and lateral illumination without blinding other road users with excessive glare. High beams provide an intense, centre-weighted distribution of light with no particular control of glare and will only be used when there are not any visible cars ahead of you, irrespective approaching or moving away.

5.7.2 Daytime running lights

Daytime running lights are located in both the front and rear of the car and generally turn on automatically. In some cars you do have an option to turn them off. They are designed to make you more visible to other vehicles, also for pedestrians. They are safety lights.

5.7.3 Fog lights

Fog lights located near the headlights, these lights and are generally mounted low in order to prevent the light from refracting on the fog and glaring back toward you (the driver). These should only be used during fog when normal headlights are not effective. While not common in the U.S., rear fog lights are mandatory in Europe. Typically, the rear fog light is a bright red light that is the same brightness as your brake lights. The rear fog light is a very bright red light; do not switch it at normal weather conditions, because it dazzles the driver behind at the rear.

5.7.4 Tail lights

Tail lights uses amber or red light, which depends on function of light. They are connected so that they light up when the headlights are switched on. This helps drivers who are behind you to recognize that you are driving or are ready for driving. Part of them switch automatically with automatic daytime running lights when starts engine.

5.7.5 Position lights

Position lights are important during the day and extremely important that you are seen at night by the driver behind you. Your car is equipped with various lights of a certain colour at the rear. Conspicuity of the rear of your vehicle is provided by rear position lamps, also called tail lights. These are required to produce only red light and to be wired such that they are lit whenever the front position lamps are lit, including when the headlamps are on.

5.7.6 Signal lights

Signal lights also known as turn signals or blinkers, these are located in the front and back of the car, beside the head and tail lights. Also, installed on front sides of car or on external rear mirrors. When activated, they indicate to other drivers that you'll soon be turning in the indicated direction of the signal and will most likely be slowing down to do so.

At the end of the turn, it usually switches off automatically.

5.7.7 Brake lights

Brake lights located to the side of your rear lights, and third at present mostly high mounted stop lamp. They signal drivers that you're slowing down or stopping. They are only activated when you apply the brakes. However, you do have to make sure they are working properly all the time. It is one of the most important lights.

5.7.8 Hazard lights

Hazzard lights also known as flashers, they are located in the front and back of the vehicle. When turned on they admit a flashing signal to warn other drivers that they are experiencing a problem. Also, you are at accident place or warning of an immediate danger on road as rocks, or of slow procession. They should only be used as warnings of distress or traffic problems. It will never be used as an illegal parking permit.

Hazard lights use signal lamps.

5.7.9 Reverse lights

The reverse lights are also called backup lights, and are of white colour. They are used to warn other vehicles and people around the car that the vehicle is about to move backwards. The reverse lights also provide some illumination of the road when the car ride back up.

5.7.10 Registration plate lamps

The number plate light is a small fixture to the back of your vehicle that shines light onto the rear number plate. Due to the plate's reflective properly it is illuminated by the light, allowing other vehicles to see it at a distance.

5.7.11 Room lamps

These are located inside the cab of your vehicle. Lamps are used to brighten the cab for the passenger or driver to safely check maps or directions, or locate items in the dark.

The light switches on and off automatically and in parallel controlled manually.

5.7.12 Car reflectors

If you use your car at night, you are required by law to have two red (one left and one right) rear reflectors fitted to your vehicle. Missing, insecure, or damaged reflectors indicate that car driving is illegal.

5.8 Lamps and optics

The combination of technical and legal requirements has shaped the evolution of automotive lighting. All of those improvements in cars created faster vehicle speeds and increased traffic density. It also created a need for better ways for drivers to see and to be seen. One of the first innovations was the development of dual-beam systems, consisting of a driving (high) beam and dipped (low) beam. The second step was bi-function incandescent bulb. Next innovation was two filaments in a single bulb, with separate electrical contacts that were switched independently. At present there is a very wide variety of both lamps and projectors. More about this you can find below.

5.8.1 An incandescent light bulb

Incandescent lamp or incandescent light globe is an electric light with a wire filament heated to such a high temperature that it glows as a visible light. The filament is protected from oxidation with a glass or fused quartz bulb that is filled with inert gas or a vacuum. Incandescent lamps commonly were used in desk (office work) lamps, table lamps, hallway lighting, closets, accent lighting, and chandeliers and so on. They provide good colour rendering and, in fact, serve as the colour standard by which all other lamps are compared. Incandescent lamps are easily dimmable, for instance, changing current. These lamps have the lowest initial cost and require no electronics. However, they have very low light efficiency. At present these lamps are replaced by other lamps, as a compact fluorescent lamp (CFL) or new light emitting diodes (LEDs) lamps. Their spectral characteristics are developed similar to an incandescent light.

5.8.2 The halogen lamp

The halogen lamp has a tungsten filament similar to the standard incandescent lamp, however the lamp is much smaller for the same wattage, and contains a halogen gas in the bulb. That is filled with a mixture of an inert gas and a small amount of a halogen such as iodine or bromide.

The halogen is important in that is stops the blackening and slows the thinning of the tungsten filament. This lengthens the life of the bulb and allows the tungsten to safely reach higher temperatures.

The emitted light spectrum shifts in shorter wavelength region and light is whiter. The bulb must be made of fused silica (quartz). The halogen is normally mixed with typically nitrogen, argon or krypton. Also, this lamp is named as quartz. It is good that this lamp does not emit ultraviolet light.

Sometimes a quartz lamp is called a lamp that emits ultraviolet light. Ultraviolet rays are created in fluorescent or arc lamps. If we use a pure quartz tube for a lamp, then we can get ultraviolet rays, but they are dangerous to health. Ultraviolet light transmits through quartz. In fluorescent lamps, the inner layer is coated with a phosphor that converts ultraviolet light into visible light, and the lamp becomes a useful source of visible light. A phosphor most generally, is a substance that exhibits the phenomenon of luminescence. Ultraviolet lamps (without phosphor layer) are used in medicine, such as disinfection of premises. If it is necessary, the ultraviolet light may be blocked with filters or special glasses [5.30-5.32].

5.8.3 Xenon arc lamp, high intensity discharge (HID) lamp

Automotive (High intensity discharge) HID may be called "xenon headlamps", though they are actually metal-halide that contain xenon gas. A xenon arc is only used during start-up to correct the colour temperature. Metal-halide lamps produce light by ionizing a mixture of gases in an electric arc. In a metal-halide lamp, the compact arc tube contains a mixture of argon or xenon, mercury, and a variety of metal halides, such as sodium iodide and scandium iodide. The lamp works similarly as electric arc welding apparatus.

The lamps consist of a small fused quartz or ceramic arc tube which contains the gases and the electric arc, enclosed inside a larger glass bulb. It has a coating filter to stop ultraviolet light outside the bulb. The result is a white-blue light that is two-three times brighter than a halogen bulb. That means not only does it light the road further ahead; it also gives better visibility in the dark and in poor weather conditions.

Xenon lights are more costly than traditional halogen bulbs. For their installation it requires special optics as projectors. They can be replaced by a qualified technician, whereas a traditional halogen bulb can be changed by anyone.

Xenon lights require about 20 000 volts (20 kV) to ignite the gas, dropping to a steady 85 volts once the light is illuminated. The current is produced and maintained by a ballast unit that steps up the vehicle's 12-volt power supply to the necessary voltage.

Also, exists problems to use that lamps. For instance, according to the of UK law, HID xenon lights are not permitted. However, European type approval regulations do allow them, and therefore they must be allowed on EU cars registered in the UK [5.33, 5.34].

5.8.4 light-emitting diode (LED) and laser diode (LD)

A light-emitting diode (LED) and laser diode (LD) are semiconductor p-n devices (diodes) that emits light when electric current flows through a structure and recombine electrons and holes [5.35, 5.36]. Word laser means light amplification by stimulated emission of radiation. Hole is physical quasiparticle (not real) which is very useful to explain many physical phenomena in solid state physics.

A hole is the absence of an electron in a particular place in an atom. The hole properties are similar to electron, which charge is positive and in an electric field moves in opposite direction than electron. In other words, a hole can pass from atom to atom in a semiconductor material. In principle it is jumping electrons from one atom to another or empty place moves in another direction, like cars in a traffic jam. When we lighting semiconductor, photons generate electrons and holes. After switch off light, electrons and holes recombine one with other and emits lights. The absorbed and emitted light energy depends on difference of energies between electrons and holes. This difference is named forbidden energy gap. Not in all semiconductors effectively recombines electrons and holes. If they can directly recombine without interaction of crystal atoms vibrations or named phonons that semiconductors are with direct forbidden band gap [4.29]. That semiconductors as GaAs, InP, GaN are useful for LED or semiconductor laser diodes. Also, we can fabricate semiconductor of n-type (negative, electron conductivity) or p-type (positive, hole conductivity). The doping with impurities takes a possibility to control type of conductivity, n- or p-type.

The structure of light emitting diode and laser diode are shown in Fig. 5.2. When electric current flows through structure, it injects electrons and holes and they recombine and emit LED lights through surface of the structure. Laser diode emits light through the end of structure. The laser diode light is more monochromatic. That means the laser emitted light line is narrow in wavelength or frequency range. The colour of the light (corresponding to the energy of the emitted photons) is determined by the energy band gap of the semiconductor. Various semiconductors and emission wavelengths presented in Table 5.6.

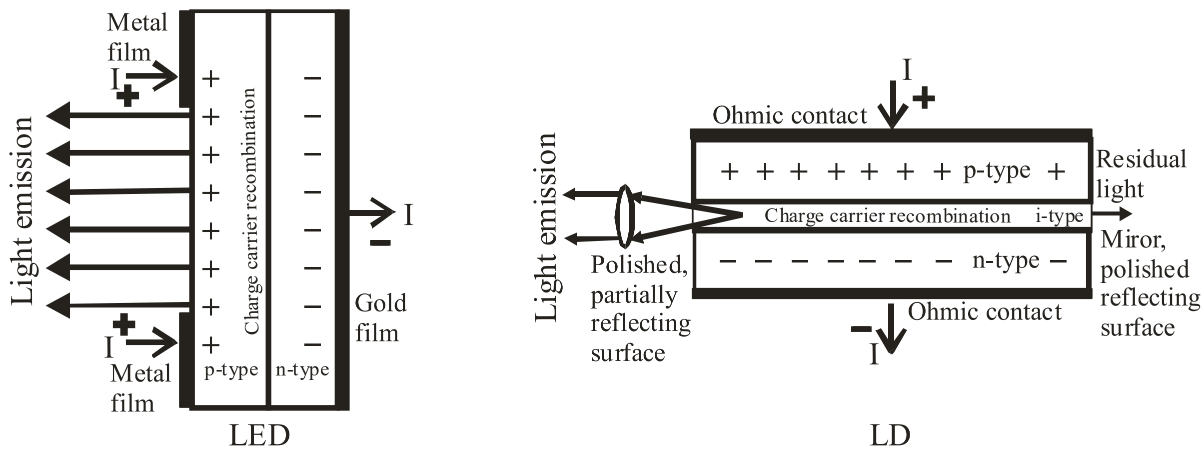


Fig. 5.2. Structure of Light emitting diode (LED) and Laser diode (LD). For LD i-type means intrinsic semiconductor region.

Laser diode (LD) structure is more complex. At the first glance the laser diode operates in the same way as LED. A laser generally requires a laser resonator or also named laser cavity. In the resonator the laser radiation can circulate and pass a gain medium which compensates the optical losses. The semiconductor structure to be placed between the mirrors. One mirror should be a semi-transparent to emit light. The mirrors can by formed by cutting ends of crystal. Other way is to use distributed Bragg mirrors, which are based on structure, for instance, GaAs/AlGaAs, with different types of refraction indexes.

The central LD intrinsic i-type layer may be replaced by nanometric quantum well (QW) structure - thin atomistic layer of different semiconductor material [4.30]. The light emission efficiency of that quantum well laser is greater than a conventional laser diode. LD requires good Ohmic contacts because high injected current density is needed, there also exist a laser light generation threshold. For this reason, LD lifetime may be shorter than LED. For LD is actual degradation problem. Laser light is a new innovation in automotive lighting. In future it may be concurrent to halogen, xenon, and LED headlight technologies.

White light is obtained by using multiple semiconductors structure or a layer of light-emitting various phosphors on the semiconductor device. Semiconductors nanoparticles as phosphors may be used too.

Table 5.6. Semiconductors and emission wavelengths of LEDs and LD.

Material	Typical emission wavelengths
InGaN / GaN, ZnS	450 - 530 nm
GaP:N	565 nm
AlInGaP	590 - 620 nm
GaAsP, GaAsP:N	610 - 650 nm
InGaP	660 - 680 nm
AlGaAs, GaAs	680 - 860 nm

The visible spectrum is the portion of the electromagnetic spectrum that is visible to the human eye. Electromagnetic radiation in this range of wavelengths is called visible light or simply light. Visible light is between 380 nm (violet) and 740 nm (red). Eye maximum sensitivity is about at 555 nm (in the green region).

5.8.5 Parameters of various automotive light sources

Photometry is the science of the measurement of light. Many different units are used for photometric measurements, that it is difficult to understand. Historically the laboratory source of light was candle and light detector was human eye. There exist many different units and sometimes it is difficult to convert one to another. For our discussion most important is visible region of electromagnetic waves. For example, incandescent wolfram bulb emits only small part of a few percent of electromagnetic waves in visible region. Highest part of emission is in infrared region and part energy converts to heat. We are speaking that this lamp is not effective. At present new light sources was discovered that emits more visible light, and have lower other losses, for instance, infrared (thermal) emission.

Parameters of various automotive light sources presented in Table 5.7. For understanding we do short introduction in measurement units. The candela is used to measure the brightness of light sources, like light bulbs. The current definition of the candela was made in 1979, in terms of the watt at only one frequency of light. Candela (cd) is defined as the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz (555 nm wavelength - green colour, human eye is most sensitive to this colour) and that has a radiant intensity in that direction of 1/683 watts per steradian (a unit of solid angle). Luminous flux (in lumens, lm) is a measure of the total amount of light a lamp puts out. From the definition 1 W ideal source emits 683 lm luminous flux and luminous efficiency (K_I) is 683 lm/W, and that means emission efficiency is 100%. From the Table 5.7 you can compare various light sources. The laser-based white light sources with a reflective phosphor's luminous efficiency $K=\Phi/P$ is about 50 lm/W. LD light sources are only on development stage [5.36].

The colour temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source. Colour temperature is measured in the unit of absolute temperature, the Kelvin K (0 K equals -273 ^{0}C). For light bulbs are: Soft White (2700 K - 3000 K), Bright White/Cool White (3500 K - 4100 K), and Daylight (5000K - 6500K), where temperature in Kelvins K. The colour temperature of sunlight above the atmosphere is about 5900 K. As the Sun crosses the sky, it may appear to be red, orange, yellow or white, depending on its position. Lifetime (t) is lamp exploitation duration.

Table 5.7. Parameters of various automotive light sources [5.28, 5.30, 5.32, 5.37].

Light source	Electric power P, W	Luminous flux Φ, lm	Luminous efficiency $K=\Phi/P$, lm/W	Efficiency $\eta=K/K_I$, %	Colour temperature T, K	Lifetime t, hours
Incandescent	60	870	14.5	2.1	2800	1000
Halogen	50	1200	24 (10-35)	3.5	2800-3400	1700-2500
Xenon, HID	35	3000	85.7	12.5	4200	2500
LED	21.5	3700	172	25	4000	25000
Ideal	1	683	683	100	-	-

5.8.6 Lights optics

The main task of the headlights of the cars is to illuminate the road during the dark hours of the day. Headlamps and their light sources are essential parts of the vehicle for safety. The lights can't be installed in any way on their own. They're required for official approval. Also, the lights are inspected by technical inspection centres.

There exist two kinds of headlights: Low beam headlights and high beam headlights. Car headlight is a light with a reflector and special lens mounted on the front of a vehicle to illuminate the road ahead in night. Headlights switches automatically at dark if equipped. To increase safety, comfort and driving ease at night, also may be equipped automatic switch from high beams to low beams or reversely. So, you don't have to remove your hand from the steering wheel to switch the beams manually.

Your headlights have two settings - high and low. High beams are used when you're driving at night on a deserted stretch of road, and offer much better visibility than low beams. Because high beams are so bright, be sure to switch to your low beams within 150 meters of oncoming vehicles and when you're approaching a vehicle from behind so you don't blind the driver ahead or behind of you. If there are no oncoming vehicles, turn on your high beam headlights.

Headlamps and their light sources are therefore safety relevant automobile parts requiring official approval. Headlamps can basically be classified into reflection type and projection type systems. Both versions are utilized in the case of automobiles [5.28, 5.38-5.41].

Parabolic system [5.41] was one of most used system. The reflector surface has the form of a paraboloid - a parabola rotated round its own axis. Watching the reflector from the front the upper section of the reflector is employed for the dipped beam.

Dipped Ellipsoidal (DE) system is projection system. DE stands for triaxial ellipsoidal describing the form of the reflector surfaces. It allows to use small headlamps with high light output. Their operation is analogous to that of a slide projector, which also works with the similar projection system. The ellipsoidal reflector reflects the light from the bulb concentrating it at the second focus. A lens projects the light onto the road. Today DE systems are used primarily for fog lamps.

Free Form (FF) system headlamps are more complex and have reflector surfaces with a free spatial form. That lamps may be calculated and optimized with the help of computers. Nearly all modern reflection type headlamp systems for dipped beam are equipped with FF reflectors.

Super DE is also projection system, but combined with FF technology. Projector headlight use a really simple design. At its most elementary form, there are three parts: reflector, lens, light source (halogen bulb, HID or LED), see Fig. 5 3.

The reflector reflects as much light as possible from the bulb. The light is reflected so that a maximum pass above the shield to the lens. The light is reflected by the reflector so that light distribution results at the height of the shield, which is then projected onto the road by the lens.

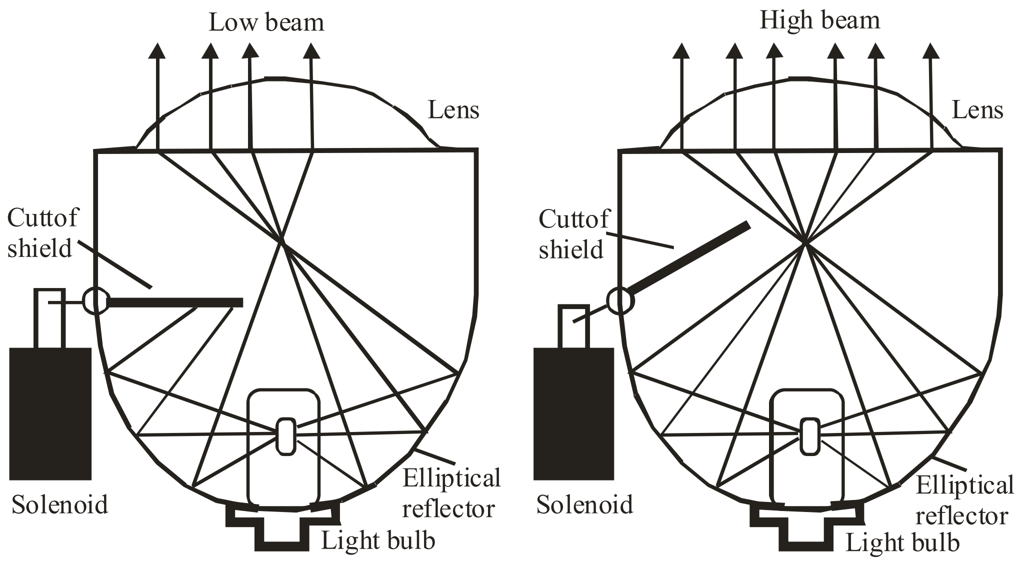


Fig. 5.3. A bifunctional headlamp projector optics: Low beam, High beam. Car computer may control solenoid actuator and light beam position.

FF technology allows greater spread and better illumination of the sides of the road. Light can be concentrated near the cut-off, achieving greater range and allowing more relaxed driving at night. This is particularly notable on long trips. Today, nearly all new projection systems for dipped beams are equipped with FF reflectors.

Projector headlights are similar to reflector headlights. They contain a bulb in a steel bowl with mirrors to act as reflectors. However, a projector headlight also has a lens that acts as a magnifying glass, increasing the brightness of the light beam. Also exists a bifunctional (Bi-Xenon) headlamp having a bulb shield operable to project a low beam light pattern or a high beam light pattern, see Fig. 5.3. Bifunctional headlamp means each projector has both a low and high beam pattern. Here, the light cut off shield inside the projector is on a hinge. When powered, the bifunctional headlamp solenoid pulls or pushes this flap/shield down to expose more light through the lens - thus creating the high beam pattern. When the high beam is deactivated, the cut-off shield retracts to its normal low beam position. If you ever researched HID headlights, you probably know it's bad to flash a HID bulb on and off repeatedly like you would when using a high beam on a dark road. Bi-xenon projector systems are not subject to this problem because when toggling between low and high beams - the bulb is constantly lit. The projector creates the high beam, not the bulb. The light shade may be regulated automatically with computer using solenoid as shown in Fig. 5.3. For energy consumption that system is not fully optimal, part energy is losing. There are also two other ways of achieving bifunctional headlamp. The first is by moving the bulb itself, so that it aims appropriately, or secondly, by using a fixed bulb with movable reflectors that achieve the same goal. At present LED lights era begins. They are used of various design and in various places of the car. About LED headlamps, please read in reviews [5.42, 5.43].

5.9 Car displays and smart phone

Car descriptions use a variety of terms to describe how information is presented in a vehicle. We will try to systematize this and introduce the shortest route so that you do not have to learn a specific car model. Automotive information systems are similar to a computer or to smartphone, because the latter is also a computer. We will also introduce the features of the smartphone. They can be directly installed in the car or accessed via connection a smartphone. Another important element is the Internet. It can be accessed via smartphone communication networks or satellite channels. Today, cellular networks are well developed in the smartphone and there is no problem with the connection and the Internet. Part of the functions is not integrated into the car's electronic system. For example, a navigation system (GPS). But it is a smartphone function, or you can buy a standalone device, which is easy to update with a computer.

In car exists two displays: 1) main information display (ID) and 2) media display (MD). The MD information can be projected on screen and system is named Head-up-Display (HUD). Some displays of the vehicle are presented in Fig. 5.4.

There are series of display names as Information display (ID), also named as Multi-information Display, Multi-function Display, Multifunction Instrument Display (MFID). The displays show warning and other information: the odometer, trip odometer, engine coolant temperature, fuel remaining, outside temperature, selector lever position, average and instant fuel consumption, driving range, average speed, etc. MFID display include digital Tachometer and Speedometer. In an automobile the display is installed in an electronic instrument cluster or display simulate all instrument cluster. The presented information is collected from car computer. Part, not very actual information can be changed for preview using Info Button. In some cars in ID can be displayed part of media information.

Media display controls and displays media audio video information. It is connected with CD player, radio, USB, Bluetooth, Navigation system (if included). Also, displays online images from backup or surrounding webcams. The main displays have a touch screen and performs input and output functions like a smartphone. In other cases, a scroll wheel is used and touchpad fitted to the centre console.

Head-Up Display (HUD) is a display that projects drive and multimedia related information onto the front windshield of the car. The Head-Up Display enhances the safety of driving by preventing drivers from taking their eyes off the road.

Head-Up Displays were designed originally to present at the usual viewpoints of the pilot the main sensor data during aircraft missions. The first civilian motor vehicle had a monochrome HUD that was released in 1988 by General Motors. HUD devices are Advanced Driver Assistance Systems (ADAS) whose objective is to enhance driving safety and efficiency thanks to the information obtained from the environment and from the vehicle.

The system operation principle is the same as projectors used at conferences. Difference is that image presented on glass or plastic screen [2.57, 5.44-5.50].

In the world of digital projection, there are three main projector technologies (names are more): DLP (DMD), LCD, TFT LCD, LCOS.

DLP or DMD (first) stands for Digital Light Processing or Digital Micromirror Device which employs a chip (silicon) comprised of microscopic mirrors and a spinning colour wheel to generate an image.

Liquid Crystal Projectors (LCD) (second) work by using three liquid crystal panels, a lamp (or other light source), a prism, and filters to create the image on the screen. It is similar to LCD TV system.

A thin-film-transistor liquid-crystal display (TFT LCD) is a variant of a liquid-crystal display (LCD) that uses thin-film-transistor (TFT) technology to improve image qualities such as addressability and contrast. TFT LCDs are used in appliances including television sets, computer monitors, other displays and projectors.

The DLP is light reflection system, whereas LCD system is light transmission system. The third system LCOS is named Liquid Crystal on Silicon chip. It is mixed transmission and reflection systems. Projection systems are also divided in three categories of lighting sources: lamp, LED or LD.

Head-Up Display devices can get name from light source (Lamp, LED, LD), or from principle of operation (DLP, LCD, TFT LCD (just TFT), LCOS).

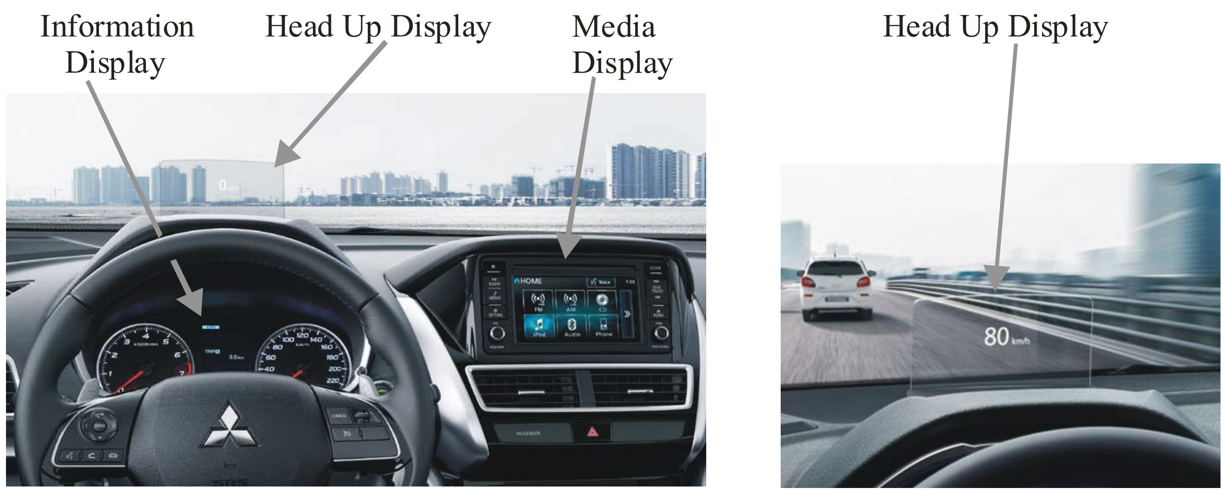


Fig. 5.4. Displays used in Mitsubishi Eclipse Cross. Adapted from [2.57].

If in your vehicle is not installed Head-Up Display system, it is not a problem. You can buy cheaper or more expensive of few hundred EUR display. Original heads-up display may project various information such as GPS maps, and vehicle information as speed, temperature and other. Additional Head-Up Display systems have different connection possibilities to OBD and smart phones. The head-up display connects to your vehicle's OBD port and projects real-time data. Other Head-Up Displays can be connected to smartphone, wirelessly too. In this case all display information comes from your phone. The driver can check information such as the time, vehicle speed, messages, incoming calls and GPS information while driving.

Using mobile phones in cars are dangerous for safety, distracting attention. However, at present this problem was solved using smartphones. Their use in the car is very simple, similar to radio. Smartphones are a class of mobile phones and of multi-purpose mobile computing devices. They are distinguished from feature phones by their stronger hardware capabilities and extensive mobile operating. The antenna transmits signals just like a radio station, and your phone picks up those signals just as a radio does. Smartphones use cell phone network technology (cell radius at 2.1 GHz is about 12 km) to send and receive data as phone calls, Web browsing, information files transferring and other features as Navigation system (GPS), Near Field Communication (NFC), Few Cameras and other. The block schema of smartphone and image fixed in it is shown in Fig. 5.5.

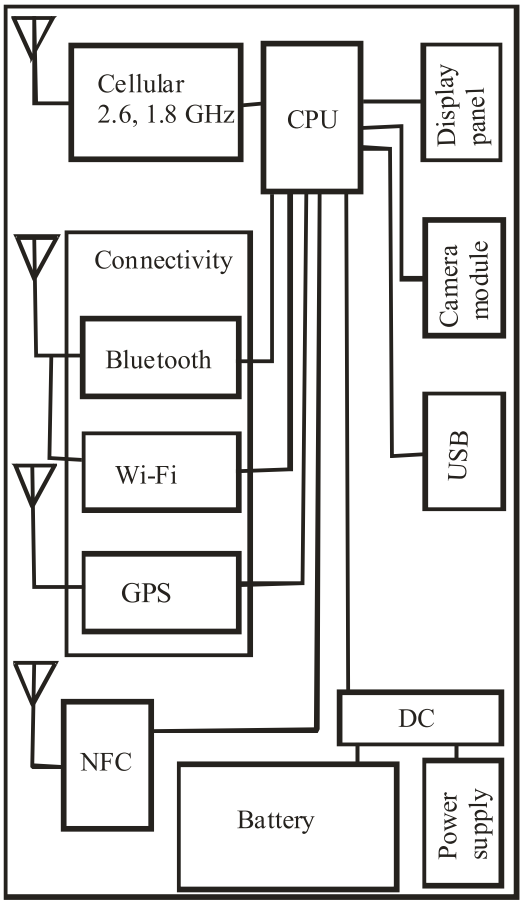


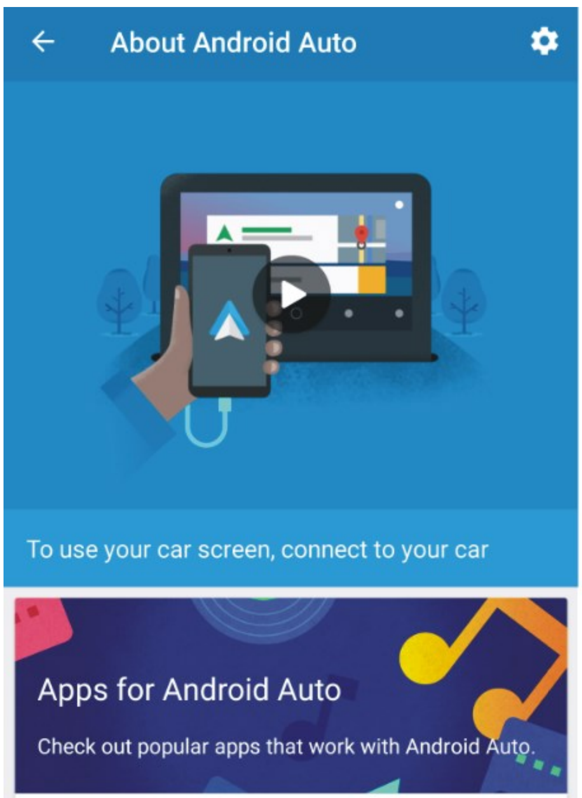
Fig. 5.5. Smartphone block schema (left). Cellular RF is 2.6 GHz, 1.8 GHz. Bluetooth (5-30 m), WiFi (32-100 m) frequency is 2.4 and 5 GHz. GPS works at 1.57542 GHz and 1.22760 GHz. Near field communication NFC operates at distance <20 cm and at 13.56 MHz frequency. The image of the Samsung Galaxy smartphone received via the Internet (right).

Smartphone integration into your vehicle depends on car model (manufacturer) [5.51-5.57]. The technology allows you to control the functions of your smartphone. By integrating your smartphone, it is easier to send text messages, make calls and navigate. Smartphone integration also supports other applications that have been downloaded to your smartphone. Thanks for the smart phone integration into car, the voice function helps you not only to read and write in the address book via voice control, but also to call contacts from address book (vehicle phone book) via voice control. Your voice will be recognized by a microphone in the overhead console, allowing you to make hands-free calls with voice commands.

Smartphone integration also consists of both Apple CarPlay or Android Auto (it is additional function of vehicle, operates if installed), and it means you can use your smartphone in a simple and safe way in the car. In simple terms, Android Auto or CarPlay takes the user interface of your Smartphone and puts it onto the infotainment screen of your car dashboard. First of all, it is required to understand what system support your car. Secondly, you have to know the smartphone can be connected: through a USB or wirelessly through Bluetooth.

Android Auto is a mobile app developed by Google to mirror features from an Android device (e.g., smartphone) to a car's compatible in-dash information and entertainment head unit or to a dashcam. Supported apps include GPS mapping/navigation, music playback, SMS, telephone, and web search. Functionality of Smartphone in the car collected in Table 5.8 and Smart phone possibilities for navigation are shown in Fig. 5.6.

Apple CarPlay is an Apple standard that enables a car radio or head unit to be a display and also act as a controller for an iPhone. If your car supports CarPlay, pair iPhone with car system and install CarPlay.



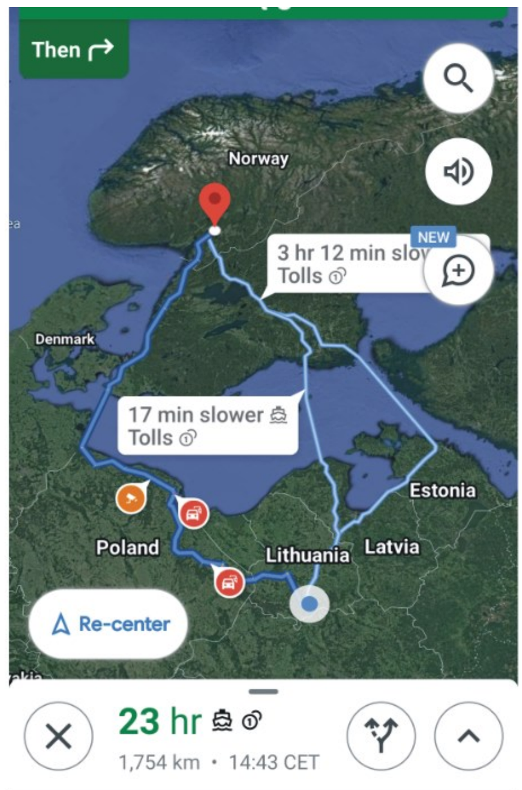


Fig. 5.6. Smart phone Android Auto (left) and navigation (right).

One of the great things about Android Auto is that it requires almost no setup. The software doesn't really have its own data - instead, it's kind of like a shell for your phone. All your contacts, music preferences, maps data, and so on gets uploaded from your phone. One thing you will need to do is download the Android Auto app on your phone.

Table 5.8. Functionality Smartphone in the car.

Operation system	Android (Google)	iOS (Apple)
Smartphones (examples)	Samsung, Google Pixel	iPad, iPod Touch and iPhone
Name of mobile applications	Android Auto	Apple CarPlay
Downloads	Google Play Store	Apple support, App Store
Application files	APK (.apk)	IPA (.ipa)
Mobile applications in Smartphone works	With and without car system	With car system
Pairing: cable, Bluetooth or WiFi	Individual, depends on car	Individual, depends on car
Navigation	Google Maps	Apple Maps and also Google Maps (as third-party)
Navigation, traffic information	Waze	Waze on iOS 12
Audio	Yes	Yes
Music	Yes	Yes
Radio	Yes	Yes
Phone calls	Yes	Yes

In different cars may by different system installed, either Android Auto (Google), or CarPlay (Apple). It depends from car manufacturer. The installation of the systems may also be affected by state laws.

CarPlay is a smarter, safer way to use your iPhone while you drive [5.56].

If you have Android 9 or below, get the Android Auto app on your phone and install it. With Android 10, Android Auto is built in, so you don't need the app to get started [5.57].

5.10 Buffeting effect in cars

Most car noises come from the engine, belts and pulleys, hoses, exhaust system, tires, suspension system, tire to pavement contact, braking, mirrors and other out said aerodynamics. However, there is one particular car noise that is not mentioned when selling a car. You will not even know about this noise and start to operate the car. Noticing this noise, you probably won't even understand what's going on. We will discuss this in the beginning without much insight into the physics.

You are driving and decided to open the window. However, you did not find a problem. What happens when a car passenger opens the rear window of passenger compartment and you can listen to the new low frequency oscillating sound. Air passing over an opening form in tiny tornadoes. In empty and closed room standing sound waves and resonances are formed. They start at some car speeds. Also, this sound can appear when you open sunroof. It's more noticeable in modern cars because they are more aerodynamic. By trying to improve gas mileage as much as possible, car manufacturers are making cars that have much smoother air flows over the car body and at the same over the windows. This phenomenon is named buffeting noise or simple buffeting. Buffeting is a wind noise of high intensity and low frequency in a moving vehicle when a window or sunroof is open and this noise makes people in the passenger compartment very uncomfortable.

Automotive OEMs invest significant effort and cost into reducing noise sources in order to improve the level of passenger comfort. Vehicle buffeting noise due to an open sunroof or side window was identified as a significant contributor to recent complaints among the wind noise. Buffeting (also known as wind throb) is an unpleasant, high-amplitude, low-frequency booming caused by flow-excited Helmholtz resonance of the inside cabin. Helmholtz resonance [5.58-5.60] or wind throb is the phenomenon of air resonance in a cavity, such as when one blows across the top of an empty bottle.

Buffeting noise mostly occurs when driving a vehicle with a sunroof or back window open, but there are isolated cases in which it also happens with a front window open. Buffeting noise is a characteristic pulsating noise generated inside vehicles when they are driven with a side window open. This low frequency noise is near or beyond the human hearing threshold. In the vehicle it reveals as a pulsation or battering causing pressure on the human body, especially the eardrums. This high sound pressure level becomes so annoying that continued exposure generates intense fatigue.

Rear Window Buffeting (RWB) is the low-frequency, high amplitude, sound that occurs in many 4-door vehicles when driven 50-110 km/h with one rear window lowered. The noise is in the 16-20 Hz frequency range. At a speed higher than 130-140 km/h, the buffeting noise can disappear, depending on the car model. Commonly, exists different individual speed ranges for generation, persistence and disappearance of buffeting noise for different cars [5.61-5.63]. In large vehicles, buffeting noise is generated during higher speed ranges.

There are few ways to avoid buffeting noise.

Two open windows on same side of the vehicle can eliminate buffeting noise effect. By opening the two rear windows simultaneously, buffeting noise exhibits a major sound pressure level and resonance frequency increase compared to a single rear open window test.

Cabin volume study shows that buffeting intensity decreases with increase of the number of occupants.

A deflector installed in the upstream of the sunroof opening can deflect the vortex away from the opening and reduce buffeting.

Sunroof opening a lot of cars has the issue of buffeting since its air flowing in and getting bounced around inside the vehicle, little open the rear windows it can eliminate the buffeting noise. With the window open you allow the air to flow in and out. But you can get other discomfort.

When you do drive at high speed with side windows down, no deflector can completely eliminate wind noise and turbulence. There will be always some noise. Please, close the windows. This essentially helps to save fuel and protect the environment.

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Chapter 6 Sensors and Actuators

Today, cars use sensors to stay in the vehicle's computer informed of what's happening around the engine. Car sensors check the intake air to fuel mixture ratio, measure the intake air temperature and other parameters, like the standard of the exhaust gas. Supported the knowledge received, the PC calculates the operation of an engine and provides parameters.

Let's say, you'll suspect that the engine isn't developing enough power and therefore the car acceleration is slowly. This might not be a mechanical failure, but a malfunction of the sensor. Either way, you ought to read a repair manual about car sensors. The primary information could also be presented on the car board display. But it's more common information: **Check Engine**. If you've got an equivalent goal or want to urge familiar with diagnostics, you will need a code reader capable of OBD II diagnostics.

The best way to solve a problem is to contact with specialist. A more qualified talk would be with a professional master if you have knowledge about the sensors built into your car and the basics of how does they work. In the vehicle you'll find a series of sensors not just for the engine but also for steering, braking, car stability, passengers' safety, comfort and more. In this chapter we'll present the car sensors and also briefly will overview car actuators [6.1-6.4].

6.1 Overview of sensors and actuators

A sensor may be a device that detects and responds to some sort of input from the physical environment. Those inputs might be light, heat, motion, moisture, pressure, or anybody of a number of other environmental phenomena. The output is usually a quantity that's converted to a human-readable display or transmitted electronically over a network for reading or further processing.

Today's engines contain sensors to inform the vehicle's computer what is going on. Car sensors check fuel-air mixture, incoming air temperature, wheel speed, pressure in manifold and many other parameters. Supported by that information your vehicle's computer calculates optimal engine performance. There are several sorts of sensor technologies as ultrasonic, capacitive, photoelectric, resistivity, inductive, or magnetic used in the automotive applications.

Actuators are an important part of electronic control systems in passenger cars and commercial vehicles. Most actuators are electric motors or electro-magnetic valves. They adjust flaps, for instance, regulating the flow of fluids or actuate pumps to create up pressure (e.g., in brake, steering, automatic transmission or other systems).

An actuator is a device that converts some kind of energy into motion, see Fig. 6.1. It also can be used to apply a force. An actuator typically may be a mechanical device that takes energy - usually energy that's created by air, electricity or liquid (brake liquid) - and converts it into some quite motion. That motion is often in virtually any form, like blocking, clamping or ejecting. Actuators are typically utilized in manufacturing or industrial applications and could be utilized in devices such as motors, pumps, switches and valves. They're vital in automotive applications.

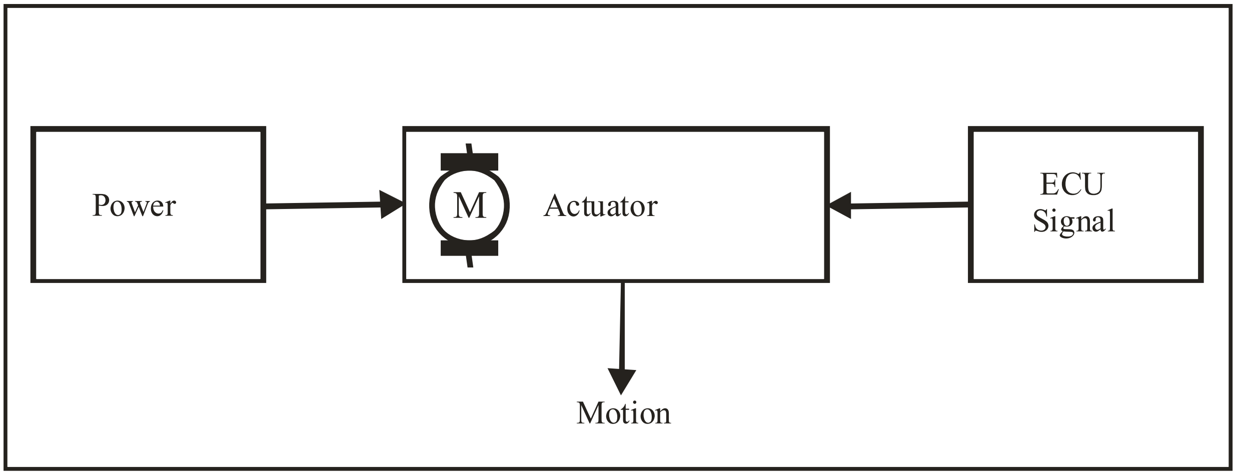


Fig. 6.1. Actuator operation principle.

Different types of actuators are installed in cars:

Pneumatic (vacuum): they generate a force. More rigorously speaking, surrounding air generates force. It can be the other way around; the compressor can generate air pressure - force.

Hydraulic: they're actuators that generate the movement from the displacement of fluids (valves of a variable suspension system).

Electromagnetic: those which operation is based on electromagnetism, either through an impact of a magnet or an electromagnet. These are usually utilized in those mechanisms of the vehicle operating with current.

Gears or other drives using various electric motors.

Mixed systems: Electromagnetic (electric motor) to hydraulic or hydraulic to mechanic (ABS, ESC).

The electronically controlled vehicle system includes basic electronic and mechatronic hardware components such as sensors and actuators. A part of actuators is presently known as Intelligent Actuators, which include integrated electronic control units and actuators. They're often called as by-wire systems. That systems are commonly utilized in self-driving cars. In conventional cars, hybrid cars and electric vehicles that systems are used only partly. This is more used for engine control systems.

6.2 Sensors and actuators, systemic view

Currently, each vehicle has an average of 60-100 sensors on board. Because cars are rapidly getting smarter, the number of sensors is projected to reach as many as 200 sensors per car. These numbers translate to approximately 22 billion (22×10^9) sensors used in the automotive industry per year by 2020 [6.5, 6.6].

In Table 6.1-6.3 are presented some systematic view to vehicle sensors and actuators [0.21, 4.47, 6.1-6.4, 6.7-6.12]. It is not full list. Shortly speaking, a sensor may be a device that changes a physical parameter to an electrical output [0.27]. As against, an actuator may be a device that converts an electrical signal to a physical output.

Table 6.1. Summary view of vehicle sensors and actuators.

System	Involved elements	Function of sensors	Function of actuators
Powertrain	Engine, transmission, on board diagnostics	Vehicle energy use, drive ability, performance	Consumption fuel, gas exhaust and power control
Chassis	Steering, suspension, breaking, stability	Vehicle handling, safety (also surrounding)	Assist power steering and braking control
Body	Occupant safety, security, comfort, convenience, information	Vehicle occupant needs	Doors, steering wheel locking. Mirrors, windows, ventilation, wipers adjustment

Table 6.2. List of sensors. Princip operation and application regions presented as well.

Sensor	Princip of operation	Application
Acceleration sensors, also known as G-force sensors, are devices that measure the acceleration caused by movement, vibration or collision	Measures vibration or acceleration of motion. Piezoelectric, Piezoresistive, Capacitive, Inductive. Mostly use MEMS technology	Initiation airbags deployment (as impact sensor), ESC, ABS Also, in Smart phones
Angular rate sensors measure angle per unit time in radians per second (rad/s)	Gyroscopic (vibrating structure gyroscope)	Yaw, Roll rate sensors (vehicle's angular velocity around its vertical axis). This sensor ties into the vehicle's traction control, stability control and antilock braking system
Mass air flow (MAF) sensor (Air-mass sensor, Mass flow sensor)	Spring-loaded air vane (flap/door) attached to a variable resistor (potentiometer) A hot wire (usually platinum) sensor	A mass (air) flow sensor is a sensor used to determine the mass flow rate of air in engine air intake. Can include heating elements and thermometers
Gearbox/transmission speed	The sensory unit is either based on the Hall-effect or has a magneto resistive system	Determine the right gears, shifting moment and shifting pressures. For cars with manual gearbox on display take recommendations shift gear. Related with cruise control unit
Crankshaft/Camshaft position	Based on pulse detection. Magnetic pick-up coils -	Crankshaft and Camshaft Position Sensors, Engine Speed Sensor

	the inductive sensor, Hall-effect sensors, magneto-resistive element (MRE) sensors, or optical (LED/ Photodetector, requires cleaning)	is to determine the position and/or rotational speed (RPM) of the crankshaft
Electronic battery sensor	Voltage, current, temperature (internal, external) measurement, analog-to-digital converters (ADCs), with CAN&LIN	Bosch, sensor supplies information about the vehicle's battery state: current, voltage and temperature are measured on the batteries negative pole niche
Fuel consumption	Instant fuel consumption calculates using: engine speed, fuel flow rate, throttle position, manifold pressure. Computer fully controls fuel injection process	Displays litter per 100 kilometres in fuel consumption display. Displays instant and average fuel consumption
Fluid level	Float Switches, a simple on/off signal. Float with magnet. It installs readily, minimizes shock, vibration, and pressure and works with a variety of fluids	Coolant or brake fluid
Fuel level/ Fuel gauge	The sending unit usually uses a float connected to a potentiometer, typically printed ink design in a modern automobile	The accuracy is low. Digital systems are more accuracy, but measurement system is on the conservative side
Oil level	Simplest is on-off mechanical contact sensor	Cars display a warning when the oil level is low
Washer Fluid level	Equipped a simple (on/off signal) two-pin probe in the tank. This requires a (slightly) conductive fluid, but most common windshield washer fluid mixtures will work	Cars display a warning when the fluid level is low
Hall effect	The Hall effect creates voltage in conductor with electric current when magnetic field is applied	That sensors are commonly used to measure the speed of wheels and shafts, to measure ignition timing, magnetic field strength and so on
Inductive	Sensor consists of a permanent magnet, a ferromagnetic pole piece (toothed wheel), coil of wire	May be crankshaft position and speed sensor, also transmission, turbine, wheels speed sensor

Knock	Vibration detection or internal pressure of the cylinder directly measurement. Vibration detection: Inductive resonant sensors, piezoelectric resonant sensors, and piezoelectric non-resonant sensors	The knock sensor is located on the engine block, cylinder head or intake manifold. This is because its function is to sense vibrations caused by engine knock or detonation. The control module uses this signal to alter the ignition timing and prevent detonation
Light (intensity)	Intrinsic photo effect. Photodetectors: photoresistors or p-n structures, which are semiconductor devices	Measure light intensity. Ambient light. Front, Rear light intensity to control mirrors dimming. Can automatically turn on car lights
Manifold absolute pressure (MAP)	MAP sensors based on capacitive, inductive, potentiometric and strain gauge techniques are commonly used for automotive pressure measurement. For example, measures electrical capacity of silicon membrane	It senses engine load (vacuum). Absolute pressure is zero-referenced against a perfect vacuum. MAP sensor is used to continuously monitor the amount of air flowing into the engine, the computer can calculate air density, adjust the amount of fuel to spray into the combustion chamber and adjust the ignition timing
Odometer	Most odometers work by counting wheel rotations. Converts the pulses to an appropriate voltage to activate a stepper-motor (for a mechanical odometer) or a printed circuit board (for a digital odometer)	Can be used few trip matter odometers with reset. You can get average fuel consumption
Speed/Speedometer	Calculate the vehicle speed based on information from the wheel speed sensors. As additional: millimetre-wavelength radar or GPS	It is a sender device used for reading the speed of a vehicle's wheel rotation. GPS also presents vehicle speed and compare with speed limit
Tachometer	Crankshaft position sensor	Measure engine's shaft rotation revolutions per minute (RPM)
Oxygen or Lambda sensor or also Air-fuel ratio (AFR) meter. The Lambda sensor and the Oxygen sensor are one and the same. Therefore, the term	The mechanism in most sensors involves a chemical reaction that generates a voltage. An oxygen sensor will typically generate up to about 0.9 volts when the	Device fitted into the exhaust system that measures oxygen content of the exhaust gasses to maintain the correct air/fuel ratio. Controls fuel consumption and exhaust gas emissions. It is very important for fuel economy and

catalytic converter with lambda control is also used which means a controlled catalytic converter	fuel mixture is rich and there is little unburned oxygen in the exhaust. The computer uses the oxygen sensor's input to regulate the fuel mixture	safety of environment
Pressure: Differential again atmospheric pressure	Pressure is force in gasses and liquids acting per surface area unite. Piezoresistive, Si membranes - capacitive	Measure various liquids and gas pressures in automotive systems: Brake, Engine oil, Fuel injection
Rain	Infrared light reflection. Used light reflection changes from wet window. A wet window reflects less light back into the sensor and the wipers turn on. At present begins use onboard cameras	Turns on and regulates speed of wipers. Sensor from reflected signal also detects amount of water (rain intensity) and adapts speed of wipers
Seat belt	When someone sits on the seat, the pressure sensor signals the occupant's weight to the ECU. The ECU then sends that data to the airbag control unit	It reads the passenger's seating position and determines is he wearing a seat belt, if not sends warning signal
Airbag	Crash sensors (also known as impact sensors): Mass or Roller type, as well accelerometers	These sensors detect a collision and cause the airbags to engage
Steering angle	Contactless induction or digital optical chopper	Measures the steering wheel position angle and rate of turn. Information important for ESC. Also, for in Lane Keep Assist, Blind Spot Detection, and Adaptive Lighting (if installed)
Temperature	Thermistors: Semiconductors (exponential dependence, resistivity decrease with temperature increase). Thermocouple, for higher T (contact of different metals generates voltage). Resistance temperature detectors (RTD) - gold, platinum, nickel or copper - resistivity increases with T	Environment or car used gases and liquids. Transmission fluid temperature. Exhaust gas temperature sensor. Engine coolant liquid, oil, fuel temperature. Measures the temperature inside the car for the climate control system to work properly

Throttle position/ Throttle valve angle	The throttle position sensor (TPS) is a potentiometric sensor with a linear characteristic curve. Non-contact type works on the principle of Hall effect, inductive or magneto resistive technology	The throttle position sensor is part of your vehicle's fuel management system. The TPS provides the most direct signal to the fuel injection system of what power demands are being required by the engine
Tire pressure (TPMS)	Si membrane - capacitor. Include thermometer, wireless RF transmitter, battery	A TPMS may reports real-time tire-pressure (if installed) information or switch on low-pressure warning light on information screen
Torque	A torque ($M=F\times r$ [Nm], F is force, r stands for shoulder) sensor or transducer converts torque into electrical signal. Uses electrical resistance, a magnetoelastic, Surface Acoustic Wave (SAW) technology	Measures steering torque, uses for ABS, ESC. Calculates the amount of the force contributing to the torque (shaft). Also, measuring and recording the torque in another rotating systems, such as an engine crankshaft, gearbox, transmission, rotor
Wheel speed	Measure the road-wheel speed and direction of rotation. Uses magnetic sensors: inductive, Hall effect or magneto-resistive	Information uses for ABS, ESC, indirect TPMS, Speedometer, and other purposes

The utilization of the optical sensors is widespread in industry. Unfortunately, it is very difficult for them to operate reliably for a long time in the vehicles. The optical components are extremely vulnerable to dirt, a closed clean environment is required. This may be said about camera sensors in safety systems.

Table 6.3. Some car actuators. Principle of operation and application regions presented as well.

Actuator	Principle of operation	Application
Airbag	Chemical explosion generates inert gas which rapidly inflates the airbag in about of 20-30 milliseconds	Passengers safety system
Seat belt pretensioner	Gas generator (explosion)	Part of the passenger's safety system
Electromagnetic relay	Electromagnetic	Lights switch, starter
DC Brushless Motors	DC/AC converter, Electromagnetic	Power steering
DC Motors	Electromagnetic	Washing, cleaning windows, fans. Windows lift, locking doors
Hydraulic and pneumatic	Electrical and mechanical pumps. Turbines	Fluid, mainly oil. Fuel. Brake fluid (hydraulic), transmission fluid
Piezo electric actuators	Piezoelectric effect	Diesel injectors
Relay/Solenoid	Electromagnetic	Locks steering wheel, locks doors. The electronic steering column lock (ESCL): locks the steering wheel when the vehicle is parked and turned off
Solenoids	Electromagnetic	Injectors. Oil control for valve timing, AT gearbox, Headlights
Stepper motors	Electromagnetic	Control light reflectors, mirrors
Note: DC - Direct current, AC - Alternating current.		

6.3 Acceleration sensors

An accelerometer or acceleration sensor is an electromechanical device used to measure acceleration forces. Such forces may be static, like the continuous force of gravity or, as is the case with many mobile devices, dynamic to sense movement or vibrations.

Acceleration (letter a) is the measurement of the change in velocity, or speed divided by time (Eq.6.1), or also proportional for spring deformation (Eq.6.2), see also Eq.6.3.

$$F = m\times a = m(dv/dt) = m(d^2x/dt^2), \quad (6.1)$$

$$F = - k\times dx, \quad (6.2)$$

where x is moving distance or the displacement (dx) - the distance the spring is deformed from its equilibrium length. F is the resulting force; k is spring constant or, in other words, force constant of the spring. A constant k depends on the spring's material and construction. The negative sign indicates that the force is working in the opposite direction with respect to the displacement.

All acceleration sensors operation is based on a simple physics principle in which Newton's second law of motion is applied to a spring-mass system

$$m \times a = m(d^2x/dt^2) = - k \times dx. \qquad (6.3)$$

The most common types of acceleration sensors use piezoelectric, piezoresistive, variable capacitance, magnetic induction type, or surface acoustic wave (SAW) registration principles.

A piezoelectric acceleration sensor utilizes the piezoelectric effect to measure the relative distance between the mass and sensor's base, and then represents the acceleration in terms of an output voltage. Quartz crystals or similar to quartz may be used as sensing elements.

In a piezoresistive acceleration sensor, a piezoresistive material is positioned so that it is deformed by the mass that changes its position and the piezoresistive material changes its electrical resistance.

A variable capacitance acceleration sensor uses changes in capacitance caused by a displacement in the mass to detect its position. Capacitive sensing system has much lower sensitivity to temperature and to influence of internal noise.

A magnetic induction type acceleration sensor uses changes in the inductance of a coil caused by a displacement in a mass made of magnetic material to detect the position of the mass.

Surface acoustic wave acceleration sensor is vibration sensors based on a SAW delay line or resonator type manufactured on a surface of a piezoelectric material plate.

Micro Electro Mechanical (Microelectromechanical) Systems (MEMS) acceleration sensors [6,9, 6,13, 6.14] consists of mechanical elements on silicon substrate. MEMS technology is very common and may include sensors, actuators, electrical and electronics devices on a common silicon substrate. MEMS is the technology of microscopic devices, particularly those with moving parts. It is tightly coupled to Si semiconductor technology. At present silicon technology is mostly developed electronic technology. The smart phones, PC computers, car computers and many more works on the basis of silicon technology.

MEMS type devices are relatively small and mechanically strong compared to other technologies. They are made by etching a tiny mechanical structure in silicon wafers where they are readily integrated with system electronics. Also, one of the important advantages of silicon is that easy may be created an insulating layer (surface passivation) by converting the silicon into silicon dioxide, named silica, fused quartz or simply glass. Silicon is the second-most abundant element in Earth's crust after Oxygen.

Various MEMS sensors can collect information from the environment through measuring parameters related with mechanical, thermal, biological, chemical, optical, and magnetic phenomena. Acceleration, pressure and other sensors based on MEMS technology are becoming increasingly popular in automotive systems.

In MEMS acceleration sensors, the sensitive element may be a comb-like structure of differential capacitors arranged in parallel on a beam (forming the seismic mass) supported by springs etched from the silicon substrate, see Fig. 6.2. A proof mass that deforms a spring in an accelerometer is sometimes called the seismic mass. Capacitive accelerometers, sometimes referred to as capacitive mass-spring accelerometers, are semiconductor sensing devices. They contain a silicon mass attached to a spring system. When force is applied to at least one end of the mass, it moves and stretches the spring. The displacement of the mass therefore represents the measured acceleration. The displacement itself is measured using three capacitor plates. There are two fixed plates (2 symmetrical half plates read as one plate) and a separate central plate - located between the 2 fixed plates. Central plate is attached to the mass. The inner capacitor moves with the mass, measuring the change in capacitance relative to the fixed plates. This alteration is converted to an appropriate output voltage to display or record acceleration data. Because the sensor's capacitance changes in reference to both fixed plates, these sensors can also show the direction of the acceleration. The change of capacity (measured voltage) is proportional to the applied acceleration. Measured voltage is often converted to digital signal.

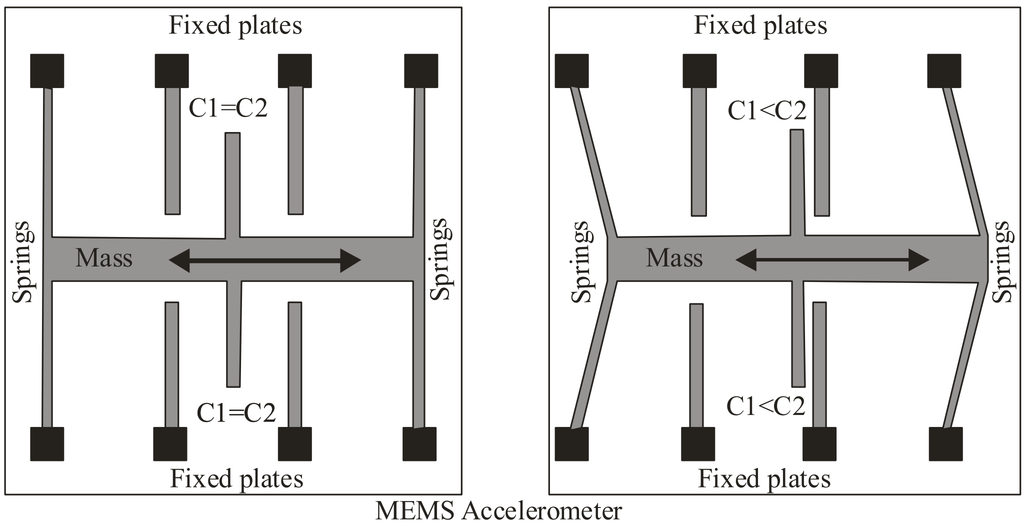


Fig. 6.2. Principal schema of MEMS (micro electro mechanical system) accelerometer. System manufactured on silicon (Si) substrate. C1 and C2 are capacitors, see Eq. 6.10.

Sensitivity of the accelerometer, sometimes referred to as the scale factor of the accelerometer, is the ratio of the sensor's electrical output to mechanical input. We will remind, a transducer is defined generally as a device that converts one form of energy to another. An accelerometer is simply a transducer that converts mechanical acceleration into a proportional electrical signal.

Typical accelerometers exhibit a mounted resonant frequency above 20 kHz. For comparison accelerometers used terms voltage mV/g_0 or charge pC/g_0 (pC is 10^{-12} Coulomb), where standard acceleration of free fall is g_0 = 9.81 m/s^2. Mostly comparison results are valid only at a certain acceleration amplitude, usually 5 g_0 or 10 g_0. Also, comparison results are valid only at one frequency, conventionally at, for example, 100 Hz). For instance, accelerometer sensitivity is 100 mV/g_0. If it is sensitivity100 mV/g_0 and you measure a 10 g_0 acceleration, you may expect a 1000 mV or 1 V output signal [6.15].

In Table 6.4 presented MEMS accelerometers application regions [6.9, 6.16]. For instance, if car speed is about 30 m/s (about 110 km/h), crash time is about 30 milliseconds, in result the impact acceleration is equal 1000 m/s^2 $\approx$100 g_0.

Table 6.4. MEMS accelerometers application regions.

No.	Application region	Application	Frequency bandwidth, Hz	Measurement range in g_0=9.81 m/s^2 units
1	Consumer	Motion, static acceleration	0	1
2	Automotive	Crash Stability	100 100	Less than 200 2
3	Industrial	Platform stability	5-500	25
4	Tactical	Weapons, craft navigation	Less than 1000	8
5	Navigation	Submarine, craft navigation	More than 300	15

In digital-output accelerometers, defines the rate at which data is sampled. Bandwidth is the highest frequency signal that can be sampled. In analog-output accelerometers, bandwidth is defined as the signal frequency at which the response falls to -3 dB of the response to DC or low-frequency acceleration. The level or range of acceleration supported by the sensor's output signal typically defined in g_0 acceleration of free fall units. This is the greatest amount (measurement unit) of acceleration can measure and represent as an output, see also Table 6.4.

Areas of application of acceleration sensors in automotive safety and control systems:

Collision detection and airbag deployment. Sensors measure intensity of collisions and initiate airbags deployments.

Electronics stability programs and control. Measures acceleration along various axes, (e.g. forward, braking and cornering accelerations, to compute relative movements and regulate them).

Antilock braking systems.

Active suspension systems. Measures longitudinal and lateral accelerations as well as vehicle roll characteristics to change damper characteristics accordingly.

Hill descent/hold control. Measures vehicle inclination and speed to regulate system.

Monitoring noise and vibrations.

6.4 Angular rate sensors. Gyroscopes

Angular rate sensors measure a change in angular velocity about an axis in degrees per second (hour) or radians per second (hour). These sensors in automotive applications most use vibrating structure gyroscopes. The main automotive application of these sensors is to determine the vehicle rotation about its vertical Z axis, named Yaw, also vehicle rotation about its lengthwise horizontal X axis, named Roll [6.3, 6.17], see also Fig. 6.3. These sensors are vitally important in electronic stability control systems.

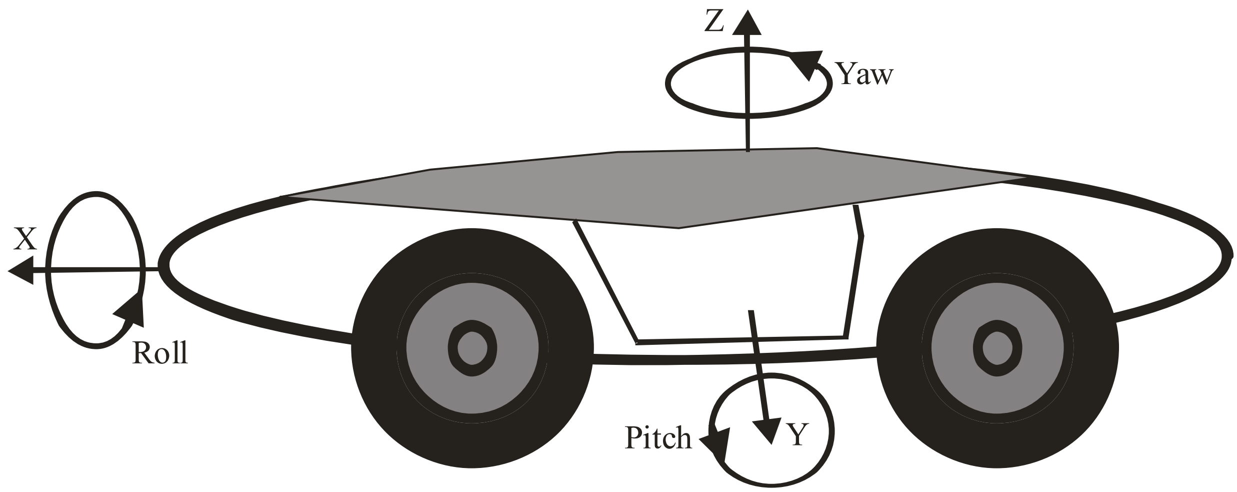


Fig. 6.3. Vehicle three rotations: Yaw, Pitch and Roll.

Three rotations Yaw, Pitch and Roll was defined in an aircraft, also in ship motion. The term Yaw was originally applied in sailing, and mentioned the motion of an unsteady ship rotating about its vertical axis. Its etymology is uncertain. An aircraft in flight is liberal to rotate in three dimensions: Yaw, nose left or right about an axis running up and down; Pitch, nose up or down about an axis running from wing to wing; and Roll, rotation about an axis running from nose to tail. The axes are alternatively designated as vertical, transverse, and longitudinal respectively. These axes move with the vehicle.

For automotive applications more actual is Yaw-rate sensor. A Yaw-rate sensor may be a gyroscopic device that measures a vehicle's angular velocity around its vertical axis. The angle between the vehicle's heading and the vehicle's actual movement direction is named slip angle, which is said to be the Yaw rate. These sensors play a key role in electronic stability control systems. Also, gyroscopic sensors are utilized in smartphones. A gyroscope measures the orientation of device. When you tilt or rotate your phone while playing videos or games, the gyro sensor adjusts the phone orientation accurately according to the phone movement.

Angular rate sensors measure a change in angular velocity about an axis in degrees per second or radians per second. These instruments use vibrating structure gyroscopes. The most automotive application of those sensors is to work out the Yaw (vehicle rotation about its vertical axis) or Roll (vehicle rotation about its lengthwise horizontal axis) angle of the vehicle. For example, the Yaw-rate sensor determines how far off-axis a car is "tilting" in a turn.

Our discussion begins with gyroscopes and below we'll present automotive angular rate sensors. A gyroscope may be used as a device measuring or maintaining orientation and angular velocity. This device can operate on different physical principles: mechanical, optical and vibrating as type of mechanical gyroscope in compact design. Widely used Micromechanical Systems (MEMS) technology for fabrication of small dimensional gyroscopes.

Today, modern gyroscopes are available in two varieties: mechanical gyroscopes and optical gyroscopes.

Mechanical gyroscopes are often divided into two categories: rotating and vibrating gyroscopes.

Mechanical rotating gyroscopes could also be divided in completely mechanical as gyroscope toy for child's and gas-bearing gyroscope during which wheel inside gyro spins at a constant rate of 19200 rpm on gas bearings, as an example, Hubble gyroscopes in Cosmos [6.18, 6.19]. Mechanical rotating gyroscopes work on the principle of conservation of angular momentum.

Vibrating gyroscopes could also be divided into various constructions by used technology and, partially, operation principles, e.g., MEMS (Microelectromechanical Systems) and SAW (Surface Acoustic Waves) gyroscopes. They work on the Coriolis effect. Deflection of an object due to the Coriolis force is called the Coriolis effect. Coriolis force initiates a moving (vibrating) body on a rotating system and is proportional to the product of the linear and angular velocities. Coriolis force is usually extremely weak. This effect in automotive mostly is used to determine rate of rotation.

Optical gyroscopes do not require mowing parts. They'll be divided into two main types as free space working Laser ring gyroscopes (LRG) and Fibre optical gyroscopes (FOG). They working principle is based on the Sagnac effect. The Sagnac effect is usually considered as being a relativistic effect produced in an interferometer when the device is rotating.

6.4.1 Mechanical gyroscope

Mechanical gyroscope is a device consisting of a wheel or disc mounted so that it can spin rapidly about an axis which is itself free to be altered in direction. The orientation of the axis is trying to keep its orientation when it is affecting by tilting of the mounting. So, gyroscopes can be used to provide stability or maintain a reference direction in navigation systems, automatic pilots, and stabilizers [6.18].

6.4.2 Optical gyroscope

Optical gyroscope is one among the newest devices, which starts after discovering lasers. Exists two sorts of optical gyroscopes. One among them is laser ring gyroscope (LRG) and the other is fibre optical gyroscope (FOG). FOG, which is similarly to LRG, rate sensors operate employing a fibre optic ring and a solid-state laser to measure rotation rates using the Sagnac effect (Sagnac interference). Sagnac discovered that light sent around a closed-loop system, in two different directions, would show a phase difference between the 2 beams when the loop is rotated. It's important FOG (also LRG) sensors haven't any moving parts. Fibre are often as long as 5 km. FOGs are used for top performance space applications and military inertial guidance systems. Some problems are with dimensions and it requires initial calibration [6.18, 6.20].

6.4.3 Vibrating gyroscope

A vibrating structure gyroscope, defined by the IEEE as a Coriolis vibratory gyroscope (CVG) may be a gyroscope that uses a vibrating structure to determine the speed of rotation [6.10, 6.21, 6.22]. The underlying physical principle is that a vibrating object tends to continue vibrating within the same plane albeit its support rotates. The Coriolis effect causes the thing to exert a force on its support, and by measuring this force the speed of rotation is often determined. If we eliminate mass from Coriolis equation, we can say that acceleration is proportional to product the velocity and an angular rate rotation.

Measuring this phenomenon is not so easy. The measured signal is very small. Measurement uses signal modulation principle. This technique is used to extract a small change from measured signal.

Vibrating gyroscopes are simpler and cheaper than conventional rotating gyroscopes of comparable accuracy. Inexpensive vibrating structure gyroscopes manufactured with MEMS technology are widely utilized in smartphones, gaming devices, cameras and lots of other applications. The actuation mechanisms used for driving the vibrating structure into resonance are primarily electrostatic, electromagnetic, or piezoelectric. To sense the Coriolis-induced vibrations within the second mode, capacitive, piezoresistive, or piezoelectric detection mechanisms are often used [6.23].

6.4.4 Surface Acoustic Waves gyroscope

Surface Acoustic Waves (SAW) gyroscope is a device, which detects a change in SAW velocity as a function of the angular rate of the medium in which the surface acoustic waves propagates. In principle it is also vibrating gyroscope. That sensors are under development. SAW gyroscopes has the potential to be the highest performing gyroscopes in the near future. SAW gyroscopic sensors more uses for tactic applications. There exist problems related with microelectronic technology [6.24].

6.4.5 MEMS gyroscope sensors

In most micromachined gyroscopes, the actuation and sensing electrodes are often designed and made as a mixture of moving parallel-plate capacitors. Automotive Yaw sensors are often built on the base of vibrating structure gyroscopes [6.10-6.12, 6.25]. MEMS gyros are small sensors most often measure angular velocity.

MEMS type gyroscope sensors are mostly the micro-mechanical capacitive sensors with oscillating elements. MEMS gyroscopes are actually based on Coriolis effect [6.26]. The principal scheme of oscillating gyroscope is analogous to the MEMS accelerometer, see Fig. 6.2, only it is more complicated in this case and also requires additional electronic components to convert signals. Vibratory sensing angular rate gyroscope works using oscillating mass (resonator). The oscillation is generated with a periodic force applied to a spring-mass-damper system at the resonant frequency. When the gyroscope is rotated, Coriolis acceleration is generated on the oscillating mass in a direction orthogonal to both the driven oscillation and the rotation. The measured acceleration is proportional to the product of angular rate and the oscillatory velocity. The resulting Coriolis acceleration can be measured by sensing the deflections of the mass. The capacitors used to sense such deflections of the mass are measured as in the accelerometer, for instance, see Fig. 6.2. Knowing velocity, we may define the angular rate of gyroscope from measured Coriolis acceleration.

Thanks to their small size and cheapness, MEMS devices have dominated in the robotic technique and also automotive market at present. In Table 6.5 are presented gyro sensors application regions [6.9, 6.23, 6.26-6.35]. Also are shown requirements for sensors stability and rotation rate. Accelerometer and gyroscope sensors are frequently utilized into one device, they'll create a very powerful array of information. Though similar in purpose, they measure different things. Accelerometer measures linear acceleration, however gyroscope senses rotation.

Table 6.5. Gyroscope sensors application. The notation deg means degrees of angle.

No.	Applications region	Bias stability, deg/h	Rotation rate, deg/s	Applications details
1	Consumer	30-1000	30-2000	Mouse, camera
2	Automotive	3.5	150-300	Yaw, Roll
3	Industrial, Tactical	1-30, 0.1-30	≥100, selectable	Stabilization
4	Tactical	0.1-1	>500	Missile navigation
5	Navigation	0.01-0.1	>400	Aeronautics
6	Strategic	0.0001-0.01	0.45, 1	Submarine (Torpedo)

6.5 Airbags. Seat belts

An airbag may be a vehicle occupant restraint system employing a bag designed to inflate extremely rapidly then quickly deflate during a collision. It consists of an airbag cushion, a flexible fabric bag, an inflation system and a crash sensor. In principle car airbag or also named as a supplemental restraint system (SRS) and seat belts systems are two independent safety systems. On the opposite hand, the seat belt, a passive safety device is at work all the time. The airbag, an active safety device, isn't always a standalone safety device. This technique is supplementary or secondary restraint system. The airbag's function is to add to the protection provided by the primary restraint system the seatbelts. Shortly we'll remind you to seat belts system, because its system electronically is connected with airbag system.

Seat belts dramatically reduce the risk of death and high injury. Among drivers and front-seat passengers, seat belts reduce the danger of death by 45%, and cut the danger of great injury by 50%. Seat belts prevent drivers and passengers from being ejected during a crash. Vehicles to come with a seat belt reminder system that provides an audible signal for 4 to 8 seconds and a warning light for a minimum of 60 seconds after the ignition is turned on if the driver's seat belt is not fastened.

Occupant Classification Systems (OCS), Seat Occupant Sensors (SOS), Occupant Detection Systems (ODS), Passenger Weight Systems (PWS) are names for the varied passenger safety systems designed to detect the particular presence of a passenger within the seat. When someone sits on the seat, the pressure sensor signals the occupant's weight to the ECU. The ECU

then sends that data to the airbag, which has its own control unit. Supported that information, the vehicle's computer turns the passenger airbag on or off. The OCS doesn't just detect weight.
In a typical seatbelt system, the belt webbing is connected to a retractor mechanism. The central element within the retractor may be a spool, which is attached to at least one end of the webbing. The retractor includes a locking mechanism that stops the spool from rotating when the car is involved in a collision.

At present belts systems are equipped with pretensioners. The seat belt pretensioner is one of many actuators involved in a pre-crash safety system. The aim of the pretensioner is to tight the belt and fix occupant to its seat. That scale back the danger of an injury. By holding the passenger tightly, this prevents them from impacting the steering wheel or dashboard, or from sliding out of their seat.

6.5.1 Belts pretensioners

The mechanical tensioner is connected to the belt by a very powerful spring that is compressed and latched in place. In a case of immediate acceleration/deceleration, the latch is unlocked and the spring is released, tightening the seat belt.

Some pretensioners are fabricated using electric motors or solenoids, but the foremost popular designs today use pyrotechnics technology to pull the belt webbing [6.36, 6.37]. In Fig. 6.4 the diagram below shows a representative model of pyrotechnics pretensioner. The central element in this actuator is a chamber of combustible gas. Inside the chamber, there is a smaller chamber with explosive igniter material. This smaller chamber is outfitted with two electrodes, which are wired to the central processing unit.

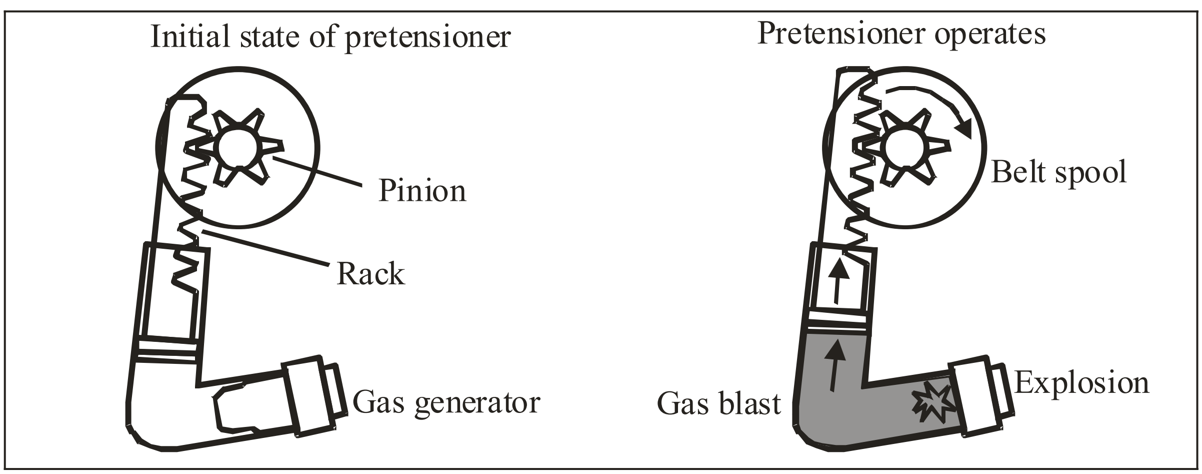


Fig. 6.4. Operating mechanism of the pyrotechnics pretensioner.

The seat belt pretensioner system is designed to work only once. After the seat belt pretensioners have been activated, they will not work again. They must promptly be replaced and the entire seat belt pretensioner system inspected by an authorized dealer.

6.5.2 Airbag

The airbag is a vehicle safety device. It's a restraining device designed to inflate rapidly during an automobile collision. It prevents the driver and passenger from striking the steering wheel or a window.

You and your passengers are often safer within the event of a collision, when a car, for instance, is provided with a 7-airbag system to supply increased safety to each seat. The front seat occupants are protected by front airbags, plus a further knee airbag for the driver to assist protect the legs during a forward collision. During a side collision, the front occupants are protected by side airbags and occupants in both rows are protected by curtain airbags extending along the sides. Airbags are a part of the Supplemental Restraint System. To decrease the danger of injury from a deploying airbag, always wear your safety belt, sit upright within the middle of the seat and don't lean against the door. Always place children 12-year-old and under within the rear seat and use appropriate child restraints. Never place a rear-facing infant restraint within the front seat. The airbag systems can differ for various cars. There are three parts of an air bag.

First, there is the bag itself, which is made of thin, nylon fabric and folded into the steering wheel or the dash board.

Second there's the sensor that tells the bag to inflate. It detects a collision force adequate to running into a brick wall at 16 to 24 km/h. Generally, airbags are triggered by sensors mounted at the front of the car that detect when the vehicle decelerates with a force adequate to hitting a solid object at a speed of quite 25 km/h. That's almost like a 50 km/h crash into an identical car.

Third, the airbags within the vehicle are controlled by a central airbag control unit (ACU), a specific type of ECU. The ACU monitors a variety of related sensors within the vehicle, including accelerometers, impact sensors (mass type sensors or roller-type sensors), side entrance sensors, wheel speed sensors, gyroscopes, brake pressure sensors, and seat occupancy sensors [6.38, 0.32]. Finally, below presented the airbag inflation system.

Air bags are literally inflated by the equivalent of a solid rocket booster. Sodium azide NaN_3 and potassium nitrate KNO_3 react very quickly to produce a large amount of hot nitrogen gas. This gas inflates the bag, which literally bursts out of the steering wheel or dashboard because it expands. The airbag system shown Fig. 6.5. After about a second later, the bag is already deflating, it has holes in it and you can go out of the car.

In an airbag, the initiator is employed to ignite the solid propellant inside the airbag inflator. The burning propellant generates nitrogen inert gas which rapidly inflates the airbag in approximately 20 to 30 milliseconds. An airbag inflator, as you would possibly have guessed, initiates the deployment of the bag within the event of a car crash. Now modern vehicles are equipped with a dual inflator, where one inflator deploys the bag during a low speed collision and therefore the other deploys the bag during a high-speed collision. Airbags contain a ballistics component referred to as an initiator, or bridge wire, which triggers the discharge of gas to inflate the airbag once it receives a signal from the crash sensor.

Crash sensors (also referred to as impact sensors), for instance, accelerometers, got to detect a collision and convert it into usable signals within milliseconds. The airbag sensor is typically bolted to the car radiator cradle. The airbag sensor senses a deceleration. During a collision it send a signal to the SRS computer unit. The computer will also use the vehicle speed, Yaw rate and seatbelt occupant information to work out.

At present cars are fitted with ultra-fast pressure sensors within the front doors to detect a collision from the side that pushes the outer door panel inwards, creating excess pressure inside the door. Many automakers recommend replacing your airbag sensors after any collision in which your car airbags explode. Other manufacturers state that their sensors will reset themselves after a collision and wish not to get replaced.

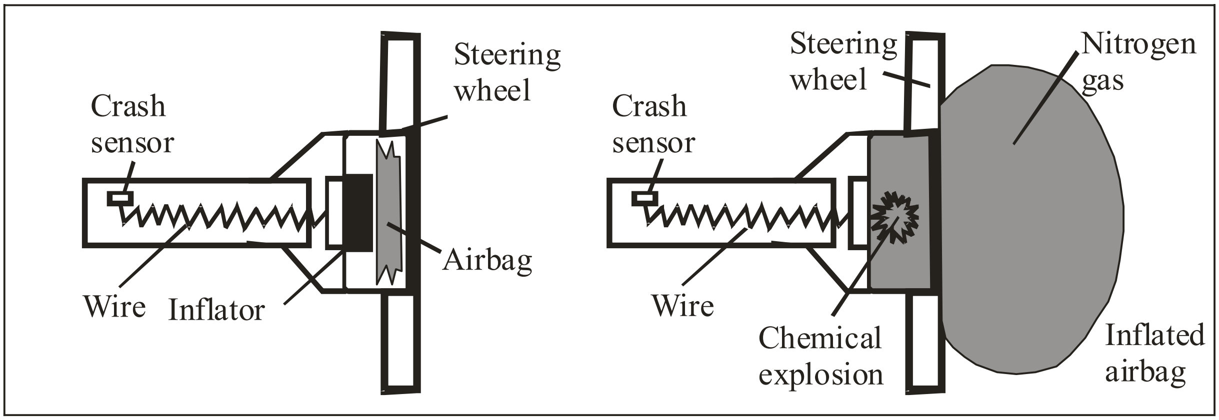


Fig. 6.5. Airbag system. Inflator ignites solid. Sodium azide NaN_3 and potassium nitrate KNO_3 react very quickly to produce a large pulse of hot nitrogen gas.

Until recently, most of the strides made in auto safety were in front and rear impacts, albeit 40 percent of all serious injuries from accidents are the results of side impacts, and 30 percent of all accidents are side-impact collisions. Many carmakers have responded to these statistics (and the resulting new standards) by strengthening up doors, door frames and floor and roof sections. But cars that currently offer side airbags represent the new wave of occupant protection. Engineers say that designing effective side airbags is far harder than designing front airbags. This is often because much of the energy from a front-impact collision is absorbed by the bumper, hood and engine, and it takes almost 30 to 40 milliseconds before it reaches the car's occupant.

During a side impact, only a relatively thin door separates the occupant from another vehicle. At present in modern cars this layer is thicker an is about or more than 20 cm. This suggests that door-mounted side airbags must begin deploying during 20 or 10 milliseconds if the side crush speed is 36 km/h or 72 km/h, respectively. An alternative choice for head protection in side impacts is the curtain airbag [6.39, 6.40]. Curtain airbags are side airbags that protect the head. They immediately activate during a side impact crash. Side curtain airbags deploy about three times faster than front airbags. They deploying from the top of the door rails above the side window. Also, they installed in place to protect the head when the car rolls over.

6.6 Hall effect sensors

Hall sensor or Hall effect sensor, a thin strip of metal features a current passing along it. The flow of electrons through a conductor form a beam of charged carriers. When a conductor is placed in a magnetic field perpendicular to the direction of the moving electrons, they're going to be deflected from a straight path. The effect is known after the American physicist Edwin Herbert Hall discovered it in 1879. Sensors like this can also be used to measure speed (for example, to count how fast a wheel or car engine cam or crankshaft is rotating).

The Hall effect is due to the nature of the current passing a conductor. Current consists of the movement of many small charge carriers, typically electrons, holes (a hole is the absence of an electron in a particular place in an atom), ions or all three. When a magnetic field is applied, these charges experience a force, called the Lorentz force. When such a magnetic field is absent, the charges follow approximately straight, line of free paths in direction of electric field between collisions with impurities, phonons (lattice vibrations), defects. However, when a magnetic field with a perpendicular component is applied, their paths between collisions are curved, thus moving charges (say, electrons) to accumulate on one face of the material. This leaves equal number of holes to be placed on another face.

In classical electromagnetism electrons move in the opposite direction of the current, holes are flowing in the same direction of the current.

One very important feature of the Hall effect is that it separates positive charges moving in one direction and negative charges moving in the opposite. The Hall effect offered the first real proof that electric currents in metals are carried by moving electrons. The Hall effect also showed that in some substances (especially p-type) the current is as moving positive holes rather than negative electrons. A common source of confusion with the Hall effect is that holes moving to the left are really electrons moving to the right, so one expects the same sign of the Hall coefficient for both electrons and holes. This confusion, however, can only be resolved by modern quantum mechanical theory of transport in solids.

When a current-carrying semiconductor is kept in a magnetic field, the charge carriers of the semiconductor experience a force in a direction perpendicular to both the magnetic field and the current. At equilibrium, a voltage appears at the semiconductor edges. The simple formula for the Hall coefficient given below is usually a good explanation when conduction is dominated by a single charge carrier. However, in semiconductors having intrinsic conductivity the theory is more complex, because in these materials' conduction can involve simultaneous contributions from both electrons and holes.

Lorentz force **F** when carrier with electric charge q (electron charge is $e=1.602\times10^{-19}$ C) moves in electric **E** and magnetic fields **H** may be expressed by formula (in vector form)

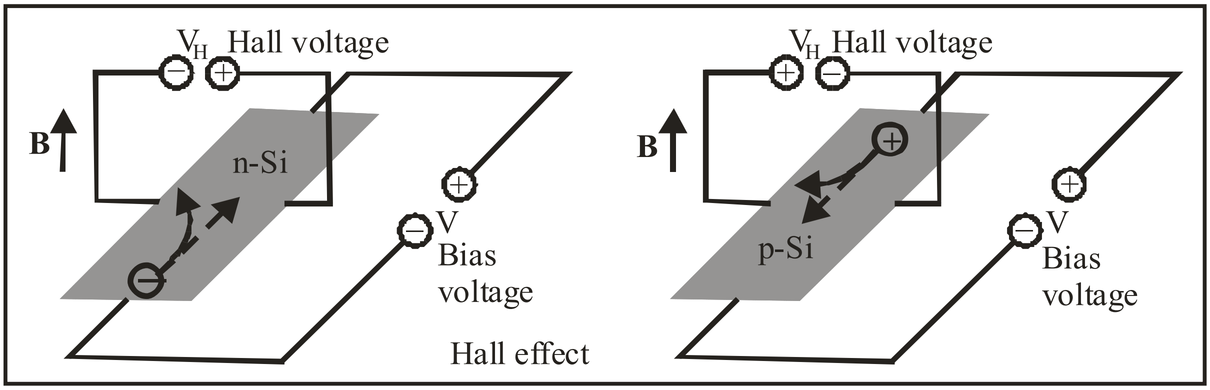
$$\mathbf{F} = q\,\mathbf{E} + q\,\mathbf{v}\times\mathbf{B}, \qquad (6.4)$$

where **B** (also called a magnetic field) is the magnetic induction $\mathbf{B} = \mu_0\mathbf{H}$ (in vacuum/air), μ_0 is magnetic constant. For moderate magnetic fields the Hall electric field can be expressed as

$$\mathbf{E}_H = [\mathbf{v}\times\mathbf{B}]. \qquad (6.5)$$

Here, $\mathbf{E}_H$ is the Hall electric field, **v** is the velocity of carriers, $\mathbf{E}=\mathbf{F}/q$. The Hall electric field depends on carrier's velocity or mobility, which equals $\mu=v/E$ ($v=\mu\times E$). Carrier mobility is a measure of how fast the charge carriers move in response to an electric field. It varies with respect to the type of semiconductor, the dopant concentration level, the carrier type (n or p type), and temperature. Electrons mobility in semiconductors is higher than that of holes, because electrons effective mass is lower. This leads to higher mobility, higher velocity, higher

Hall electric field, higher output signal. In Fig, 6.6 are shown principal schema of Hall sensors n-type (electronic conductivity) and p-type (hole conductivity). The Hall voltage is equal $V_H=E_H \times w_H$, where w_H is distance between Hall contacts.



Fig, 6.6. Principal schema of Hall sensor n-type (electron conductivity) and p-type (hole conductivity) semiconductors. **B** is the magnetic induction (magnetic field).

The key factor determining sensitivity of Hall effect sensors is a high electron mobility. As a result, the following semiconductor materials are especially suitable for Hall effect sensors: gallium arsenide (GaAs), indium phosphide (InP), also are used Silicon (Si), or germanium (Ge). That semiconductors are with wide forbidden band gaps, and at room temperature are near insulators and requires that will be doped with donor impurities, which create free electrons. It is important to recall that electrons have higher mobility than holes and create higher Hall voltage [4.29].

Also, can be used narrow forbidden band gap semiconductor as indium antimonide (InSb), which have high concentration of free carriers at room temperature and high mobility of electrons. For more reading see in [6.41, 6.42].

Hall-effect sensor will be able to detect very precisely variations of the magnetic field. That sensors may be used to measure rotating part speed, for example, to count how fast a wheel or car engine cam, or crankshaft is rotating.

The Hall effect sensors used advanced semiconductor technology. The Hall element is constructed from a thin sheet of semiconductor material with output connections perpendicular to the direction of current flow. When subjected to a magnetic field, it responds with an output voltage proportional to the magnetic field strength. The voltage output is very small in the range of microvolts (μV) and requires additional electronics to amplify signal to useful voltage level of a few volts (V). When the Hall element is combined with the other electronics, it forms a Hall sensor. The heart of every Micro Switch Hall effect device is the integrated circuit chip that contains the Hall element and the analog signal or digital signal electronics. In Fig. 6.7 presented is operation schema of Hall and inductive sensors for comparison. We shortly comment inductive sensor. An inductive sensor is a device that uses the principle of electromagnetic induction to detect objects.

The induced voltage U in the coil according to Faraday's/Lenz's law is equal to the rate of change of magnetic flux Φ_B through the circuit

$$U = - N(\Delta\Phi_B/\Delta t), \quad (6.6)$$

where N is circuit loops number, Δt is a time difference. The induced voltage in a circuit is proportional to the rate of change over time of the magnetic flux through that circuit. In other words, the faster the magnetic field changes, the greater will be the voltage in the circuit. Hall effect sensors have an advantage over inductive sensors in that, that while the inductive sensors respond to a changing magnetic field, then the Hall effect sensors can detect static (non-changing) magnetic fields.

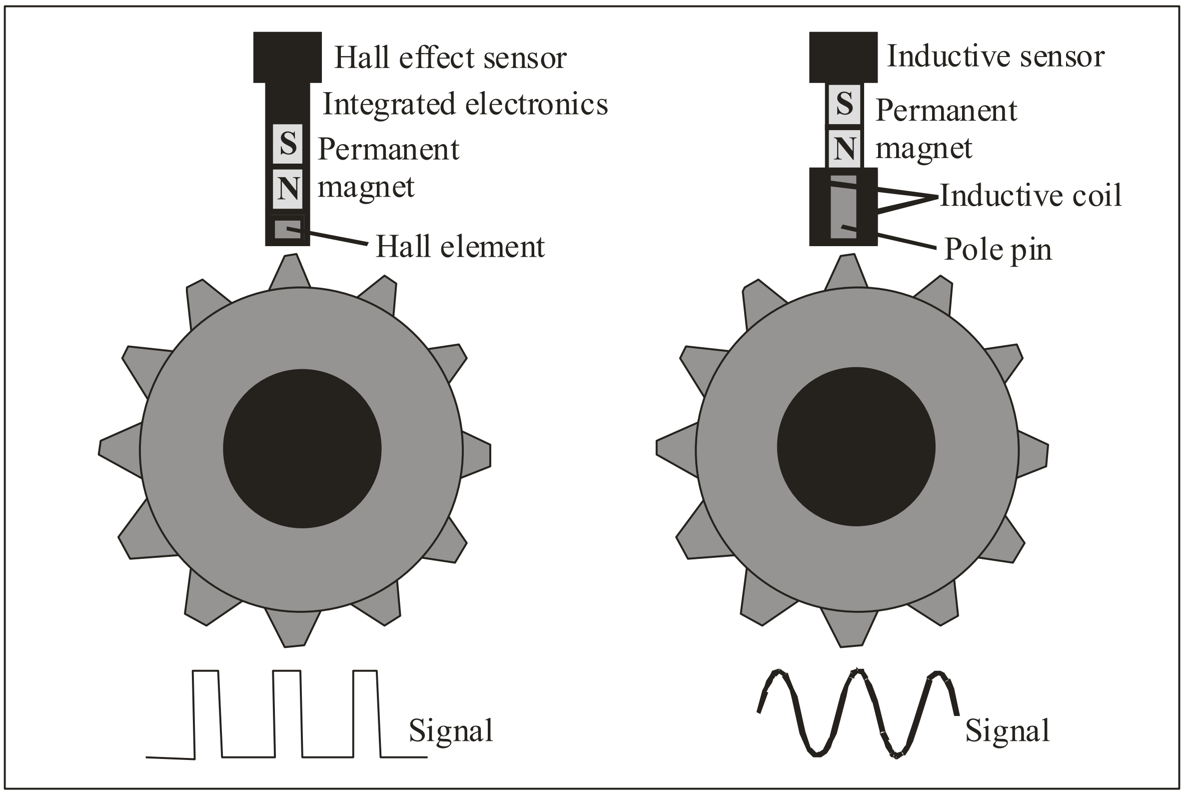


Fig. 6.7. Hall Effect and Inductive sensors.

Although the Hall effect sensor is a magnetic field sensor, it can be used as the principle component in many other types of sensing devices (current, temperature, pressure, position, etc.). Hall effect sensors can be applied in smartphone and used for electronic compass (requires to install an additional program).

In automotive Hall effect sensors are used in series of applications. For instance, Automatic transmission gears position, Wheel speed sensors, Crankshaft and Camshaft position detection, Throttle position detection, Ignition timing detection, Valve position sensors, Door Open and Close Detection and for more other applications [6.43, 6.44].

A multipole ring can be used as an impulse wheel as shown in Fig. 6.7. Also exist other systems in which magnets with permanent alternating poles are integrated in rotating disc. In this case magnet is not required inside a detector. When the wheel turns, the magnetic field in the sensor changes [6.45]. The Hall effect sensor is multipurpose sensor and is widely used in automotive applications.

6.7 Oxygen (Lambda) sensor system

An oxygen sensor or lambda sensor system, where lambda refers to air fuel equivalence ratio, usually denoted by λ is an electronic device that measures the proportion of oxygen (O_2) in the gas or liquid being analysed. An air/fuel ratio meter monitors the air/fuel ratio of an internal combustion engine. Also, it called air/fuel ratio gauge, or directly air-fuel gauge. They read the voltage output of an oxygen sensor, sometimes also called shortly air/fuel ratio (AFR) sensor or more simply lambda sensor.

In order to reduce emissions, modern cars are designed to carefully control the amount of fuel they burn. The Lambda sensor is a critical component in this process. Its goal is to work together with the car's fuel injection system, catalytic converter, exhaust gas recirculation (EGR) system, air meter and electronic control unit (ECU) to achieve the lowest possible output of environmentally harmful engine emissions, for instance, see Fig. 6.8. The Lambda sensor monitors the percentage of unburned oxygen present within the car's exhaust gases. This data is fed to the car's ECU, which adjusts the A/F (air/fuel) mixture. The right air/fuel mixture enables the Catalytic Converter to run efficiently. This exhaust gas cleaning system removes as many of the harmful emissions as possible from the exhaust before it leaves the car [2.12, 2.13]. Oxygen (Lambda) sensor system presented in Table 6.6. and visualized in Fig.6.8.

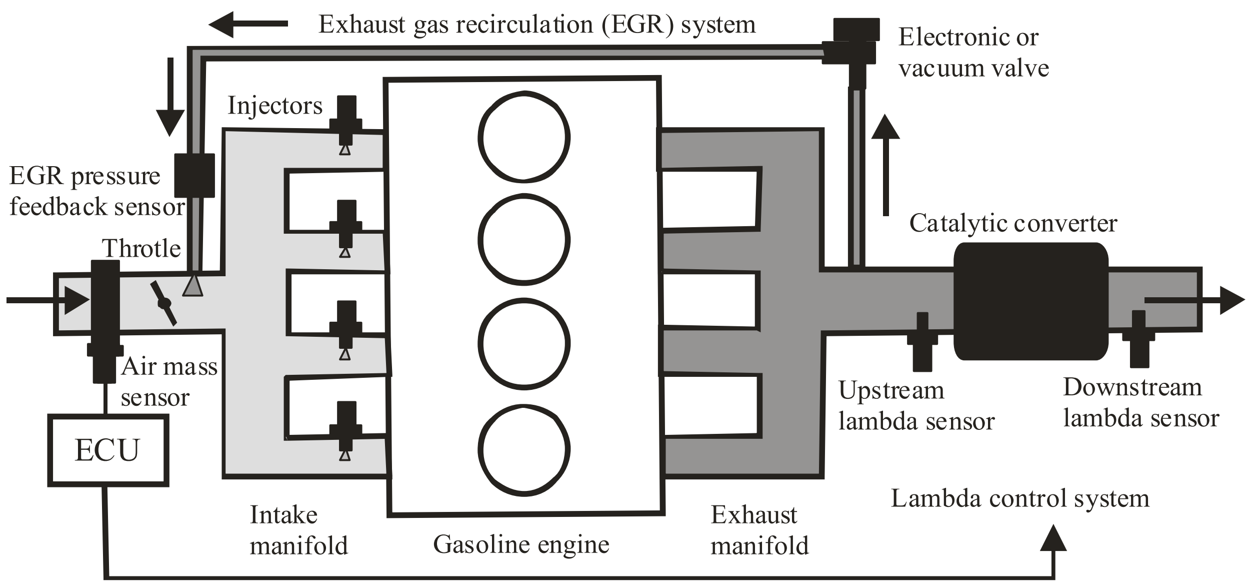


Fig. 6.8. Internal combustion engine (gasoline) lambda control and exhaust gas recirculation systems.

Consistent with whether the oxygen content within the exhaust gas is just too high (a lean mixture) or too low (a rich mixture) the Lambda Sensor transmits a fast-changing, fluctuating voltage signal to the ECU. The ECU responds to the present information by adjusting the air/fuel mixture entering the converter. The goal is to stay the air/fuel ratio on the brink of the stoichiometric point, which is that the calculated ideal ratio of air to fuel entering the catalytic converter. Theoretically, at this ratio, all of the fuel is going to be burned using most of the oxygen within the air. The remaining oxygen must be precisely the right quantity for the catalytic converter to function efficiently.

Table 6.6. Oxygen (Lambda) sensor system and other elements related with that system presented as well.

No.	Element	Operation principle	Application
1.	Oxygen (Lambda) Sensor	Zirconia sensor measure oxygen amount in exhaust gases. Zirconia (ZrO_2) is based on an electrochemical fuel cell (the Nernst cell)	2 or 4 units (placed pre- and post-catalyser). Monitors the air/fuel ratio. Economy of fuel. Minimize toxic gas
2.	Fuel Injectors	Solenoid, piezo	Controls injected fuel amount
3.	Air Meter	Mass airflow sensor: air flow change temperature and electrical resistance of sensor	Controls air flow rate
4.	Catalytic Converter	For catalysing a redox reaction uses precious metals such as platinum or palladium	Converts combustion engine exhaust toxic gases into less-toxic
5.	Exhaust Gas Recirculation (EGR)	Use EGR valve. It controls vacuum or electronic unit	To decrease gases NO_x to a minimum

In the combustion reaction, oxygen reacts with the fuel, and the point where exactly all oxygen is consumed and all fuel burned is defined as the stoichiometric point. With more oxygen (over stoichiometric combustion), some of it stays unreacted. Likewise, if the combustion is incomplete due to lack of sufficient oxygen, fuel remains unburned.

Different hydrocarbon fuels have different contents of carbon, hydrogen and other elements; thus, their stoichiometry varies.

The value of the coefficient λ (lambda) is that the ratio of the particular air/fuel ratio (AFR) to be stoichiometric. For gasoline engine air/fuel ratio (AFR) is equal to 14.7: 1 the value of $\lambda = 1$. When the engine is running on a rich mixture, then $\lambda < 1$, and engine emissions contains unburnt fuel. Air/fuel rates by mass for various fuel types presented in Table 6.7 [6.46-6.48].

Table 6.7. Air/Fuel Rate by mass for various fuel types.

No.	Fuel type	Chemical formula	Main Reaction	AFR (by mass)
1.	Gasoline/Petrol	C_8H_{18}	$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$	14.7:1
2.	Autogas liquid petroleum gas (LPG), 60% propane & 40% butane	propane C_3H_8 butane C_4H_{10}	$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ $2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$	15.67:1 15.44:1
3.	Ethanol	C_2H_5OH	$C_2H_6O + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$	9:1
4.	Diesel	$C_{12}H_{26}$	$2\ C_{12}H_{26} + 37\ O_2 \rightarrow 24\ CO_2 + 26\ H_2O$	14.5:1
5.	Natural gas (Methane)	CH_4	$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$	17.2:1
6.	Hydrogen	H_2	$2\ H_2 + O_2 \rightarrow 2\ H_2O$	34.3:1
For example, to burn completely 1 kg (about 1.35 litter) of gasoline fuel, we need 14.7 kg of air or in cubic meters 12.25 m³ (air density at room temperature is about 1.2 kg/m3).				

Below we shortly overview Oxygen (Lambda) Sensor, Catalytic Converter and Exhaust Gas Recirculation (EGR) system.

6.7.1 Oxygen (Lambda) sensor

Lambda sensor works in a result of the varying amounts of oxygen in the measured system [6.49-6.53]. The zirconium dioxide (ZrO_2), or zirconia, lambda sensor is based on a solid-state electrochemical fuel cell called the Nernst cell. Its two electrodes provide an output voltage corresponding to the quantity of oxygen in the exhaust gas relative to that in the atmosphere. The signal sends to the on-board computer or Engine Control Unit, which in turn regulates the air fuel mixture to the desired optimal level.

The detector on an oxygen sensor is usually a ceramic cylinder plated inside and out with porous platinum electrodes and protected in a housing which protects it against mechanical effects and facilitates mounting. The ceramic body is formed of stabilized zirconium dioxide. Its surfaces are coated with electrodes made of a gas permeable platinum layer. The sensors only work effectively when heated to approximately 316 °C, so most newer lambda probes have heating elements.

The outside of the cylinder is exposed to the hot exhaust gases, while the inside is vented internally through the sensor body or wiring to the surface atmosphere. Zirconia-based sensors require a very small supply of reference air from the atmosphere. A voltage is produced by the difference within the two amounts. If the quantity of oxygen within the exhaust is closer to the quantity within the air, the engine is lean and therefore the voltage is low (normally 0.1 to 0.3 volts). If the engine's exhaust is rich, the voltage is higher (generally 0.8 to 0.9 volts).

The heating elements of oxygen sensors are typically controlled in an open loop with a pulse voltage. The modern sensors often have heating elements that are controlled in a closed loop system. The measured resistance of the ceramic indicates the temperature, so the energy needed to hold the temperature constant can be simply calculated. Closed-loop system control assures a more reliable signal.

More progressive is broadband or named wideband oxygen (lambda) sensor or also, as air/fuel (A/F) sensor [6.54, 6.55]. It includes two similar construction as previously discussed sensors in one unit, just one operates as registration, other works as oxygen pump. The sensor consists of three parts: pump cell, measurement chamber and measurement cell.

The pump cell and measurement cell contain a zirconium dioxide (zirconia) plate to which a thin layer of platinum is applied on each side. When an oxygen concentration difference exists between the 2 sides, a voltage difference is going to be present between the 2 platinum plates. This voltage depends on the concentration difference and is about 450 mV (at operation point 0.9/2 V) for a perfect mixture. The measurement cell is in touch with the surface air on one side and to the measurement chamber at the opposite. Opposite of the measurement cell, a pump cell is placed which may pump oxygen into or out of the measurement chamber by means of an electrical current.

A little amount of exhaust gases can flow into the measurement chamber through a little channel. This will change the oxygen concentration in the measurement chamber, changing the measurement cell voltage from its ideal value of 450 mV in principle. To return then measurement cell back to 450 mV, the ECU sends a current through the pump cell. Depending on the direction and amount of current, oxygen ions can be pumped into or out of the measurement chamber to return the measurement cell voltage to 450 mV. For controlling air/fuel rate is employing current through a pump cell.

When a rich mixture is burned, the exhaust gases contain little oxygen and a current is sent through the pump cell to pump more oxygen into the measurement chamber. Conversely, when a lean mixture is burned, the exhaust gases contain a lot of oxygen and therefore the current through the pump cell is reversed to pump oxygen out of the measurement chamber. Depending on the magnitude and direction of the current, the ECU changes the amount of injected fuel. When an ideal mixture is burned, no current flows though the pump cell and therefore the amount of injected fuel remains unchanged. This sensor requires more electrical contact wires up to 6 (may be organized with 5), where 2 requires for heating.

For oxygen sensors are often used other materials. However, for automotive applications are specific conditions and just some other materials can be used, for instance, TiO_2 sensor [6.56, 6.57]. Titanium sensors do not generate their own voltage as the Zirconia type do. Instead, the resistance of the detector changes in response to the oxygen present within the exhaust gases. The ECU uses slightly different circuitry to sense the changes which uses a precision voltage reference, and therefore the two types are not interchangeable. The output response of the Titanium sensor is extremely almost like the Zirconia. In short, electrical resistance increases when air/fuel mixture is lean and decreases when air/fuel mixture is rich.

However, common is Zirconia O_2 sensor.

6.7.2 Catalytic converter

A catalytic converter is an exhaust emission control device that converts toxic gases and pollutants in exhaust gas from an internal combustion engine into less-toxic pollutants by catalysing a redox reaction (an oxidation and a reduction reaction). Catalytic converters are used in gasoline or diesel internal combustion engines in exhaust systems to provide a site for the oxidation and reduction of toxic by-products (such as nitrogen oxides, carbon monoxide, and hydrocarbons) of fuel into less hazardous substances such as carbon dioxide, water vapor, and nitrogen gas.

Transition metals are often used to catalyse redox reactions (oxidation, hydrogenation). The noble metals are a group of metals that resist oxidation and corrosion in moist air. The noble metals are not easily attacked by acids. Platinum and gold dissolve in the acid solution "aqua regia". On the other side, not all corrosion-resistant metals are considered to be noble metals. Transition metals are good metal catalysts because they easily lend and take electrons from other molecules.

A catalyst is a chemical substance that, when added to a chemical reaction, does not affect the thermodynamics of a reaction but increases the rate of reaction. The short list of chemically noble metals (those elements upon which almost all chemists agree include ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), osmium (Os), iridium (Ir), platinum (Pt), and gold (Au). Catalytic converters are usually used with both gasoline or diesel internal combustion engines [2.12, 2.13, 6.58-6.60]. Since hybrids have two power sources - electric and petrol or diesel - the catalytic converter is used less frequently to process pollutants.

The reduction catalyst uses platinum and rhodium to help reduce the NO_x emissions. When a NO or NO_2 molecule contacts the catalyst, the catalyst rips the nitrogen atom out of the molecule and holds on to it, freeing the oxygen in the form of O_2. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N_2. There is an oxygen sensor mounted upstream of the catalytic converter, meaning it is closer to the engine than the converter. This sensor informs the engine computer how much oxygen is in the exhaust.

Many recently produced vehicles feature a second Lambda sensor mounted after the Catalytic converter (downstream lambda sensor), as well as a Lambda sensor placed before it (upstream lambda sensor). The upstream lambda sensor is the control sensor, assisting the engine ECU to control the air/fuel ratio. The downstream lambda sensor is the monitor sensor, monitoring the function of the Catalytic converter.

The engine computer can increase or decrease the amount of oxygen in the exhaust by adjusting the air-to-fuel ratio. This control scheme allows the engine computer to make sure that the engine is running at close to the stoichiometric point, and also to make sure that there is enough oxygen in the exhaust to allow the oxidization catalyst to burn the unburned hydrocarbons and CO.

The catalytic converter does a great job at reducing the pollution, but it can still be improved substantially. One of its biggest shortcomings is that it only works at a fairly high temperature. When you start your car cold, the catalytic converter does almost nothing to reduce the pollution in your exhaust.

Catalytic converters require a temperature of 400-600 °C to efficiently convert harmful exhaust gases into nonharmful gases, such as carbon dioxide and water vapor [6.61]. Catalytic converters in diesel engines do not work as well in reducing of NO_x. One reason is that diesel engines run cooler than standard engines, and the converters work better as they are heated up. They can possibly electrically be heated when engine is cold.

The catalytic converter has three simultaneous functions [6.58, 6.62]:

1. Reduction of nitrogen oxides into elemental nitrogen and oxygen.

$$NO_x \rightarrow N_x + O_x \quad (6.7)$$

2. Oxidation of carbon monoxide to carbon dioxide.

$$2CO + O_2 \rightarrow 2CO_2 \quad (6.8)$$

3. Oxidation of hydrocarbons into carbon dioxide and water.

$$C_xH_{4x} + 2\times O_2 \rightarrow CO_2 + 2\times H_2O \quad (6.9)$$

There are two types of systems' running in a catalytic converter, first is lean and second is rich. When the system is running lean, there is more oxygen than required, and the reactions therefore favour the oxidation of carbon monoxide and hydrocarbons (at the expense of the reduction of nitrogen oxides). On the contrary, when the system is running in rich regime, there is more fuel than needed, and the reactions favour the reduction of nitrogen oxides into elemental nitrogen and oxygen (at the expense of the two oxidation reactions). With a constant imbalance of the reactions, the system never achieves 100% efficiency.

One interesting fact: converters can store an extra oxygen in the exhaust stream for later use. This storage usually occurs when the system is running lean. The gas is released when there is not enough oxygen in the exhaust stream. The released oxygen compensates for the lack of oxygen derived from NO_x reduction, or when there is hard acceleration and the air-to-fuel ratio system becomes rich faster than the catalytic converter can adapt it. In addition, the release of the stored oxygen stimulates the oxidation processes of CO and C_xH_{4x}.

Need to understand that, without the redox process to filter and convert the nitrogen oxides, carbon monoxides, and hydrocarbons, the air quality (especially in large cities) becomes harmful to the human being.

When working properly the converter should not affect fuel economy, but it can to reduce this if it becomes clogged or damaged.

In conclusion, catalytic converters are targets for thieves. Leave the car in a safe or well-viewable and well-lit place.

6.7.3 Exhaust gas recirculation (EGR) system

Exhaust Gas Recirculation (EGR) system is installed between the intake and exhaust manifolds [2.12, 2.13]. The system includes EGR valve. It adjusts the quantity of recirculated exhaust gas back to the intake manifold. Intake vacuum in the intake manifold sucks exhaust gas back to the engine. The quantity of recirculation gas requires to be closely controlled. In other cases, it can have the equivalent effect of engine performance, idle quality, and drive ability due to a huge vacuum leak.

The amount of exhaust gas returned into the intake manifold is only of about 5-10% of the total, but it is enough to dilute the air/fuel mixture to have a cooling effect on engine combustion temperatures. Diluting the intake air with exhaust gases makes the air/fuel charge less combustible. The EGR is only activated at defined operation stages that vary with specific vehicles. This keeps combustion temperatures below 1500 ^{0}C to reduce the reaction between nitrogen and oxygen that forms NO_x [6.63-6.65].

When the engine is idling, the EGR Valve is closed and there is no Exhaust Gas Return flow into the intake manifold. The EGR Valve remains closed until the engine is warm and begins operating under load. As the load and combustion temperature increase the EGR Valve is opened and begins to return exhaust gas into the intake manifold.

Older EGR systems use a vacuum or solenoid regulated EGR valve while newer vehicles tend to possess an electronic (electric or electromotive) EGR valve to regulate exhaust gas recirculation. The ECU controls the EGR flow by opening or closing the EGR valve with a step motor. The EGR flow is monitored by the manifold absolute pressure (MAP) sensor, mass air flow sensor and therefore the air/fuel ratio sensor. The EGR valve delivers a controlled reduction of oxygen content to the combustion process by introducing exhaust gas into the air/fuel charge to the cylinder at the intake manifold, causing a slower explosion within the cylinder and lower combustion temperature and pressure.

The EGR system works by recirculating exhaust gases back to the engine so as to lower cylinder temperatures and NO_x emissions. The EGR pressure feedback sensor, also referred to as the delta pressure feedback sensor, may be a sensor that detects the pressure changes within the EGR system. The EGR pressure feedback sensor on your vehicle is required for monitoring the amount of exhaust gases in your engine system and recirculating these gases back for a more complete burn. The sensor itself seems like a little rectangular box and is usually found near the side of the intake, for instance, see Fig. 6.7.

An EGR valve controls and regulates a proportion of the exhaust gas into the inlet of the engine. The most reason for this is to reduce Nitrogen oxide (NO_x) levels at the combustion stage. When the air/fuel mixture is burnt in the combustion chamber the formation of Nitrogen oxide increases as the temperature rises.

A car engine and fuel system are complex systems. It may by shortly defined, there are three engine components that can be assigned the most blame for this fuel mileage reduction, if the engine does not properly work:

1. Oxygen Sensor. It unable properly to report the air-fuel ratios through voltage generation. Symptom, lower fuel efficiency.

2. EGR Valve. The exhaust gases enter the intake manifold only at certain times. One among the primary symptoms of a problem with the EGR valve is engine performance issues. A clogged or malfunctioning EGR valve can disrupt the vehicle's air-fuel ratio, which may cause engine performance issues like a discount in power, acceleration, and even fuel efficiency.

3. Fuel Injectors. They can also be faulty, dirty. Starting engine problems, lower power, increased fuel consumption.

6.8 Direct Tire pressure monitoring system (TPMS)

Exist two tire pressure monitoring systems (TPMS) named as direct and indirect system. Indirect Tire Pressure Monitoring Systems are the systems that do not have air pressure sensors inside or outside the tires. Rather, they detect a low tire profile by comparing relative wheel speeds via the Anti-lock Brake System (ABS) wheel speed sensors. When a tire loses air, its diameter decreases slightly. This method was discussed in paragraph 3.10 Indirect tire pressure monitoring.

In this chapter we discuss at the present more common direct TPMS [6.66]. The system is extremely simple. Requires only measure pressure in the tire. The problem arise that needs measure pressure in rotating tire which changes temperature and works in extreme conditions. Also requires measured results convert to the electronic form to send wirelessly by RF electromagnetic waves. A really efficient system is required, which consumes little or no electricity. The amount of energy is extremely limited, only a little battery.

6.8.1 Introduction in direct TPMS

Direct tire pressure monitoring systems refers to the use of a pressure sensor directly mounted on the wheels or inside tires of a vehicle. The pressure sensor installed inside the tire is used mostly. Measured data is sent subsequently to the vehicle receiver using a pressure transducer. The car computer sends a signal to warn the driver of under or over inflation of a tire.

Direct TPMS utilizes a sensor in each wheel, which transmits a radio frequency signal to a receiver mounted within the vehicle. This signal includes information about tire pressure, temperature, and battery. These systems will either be more modern or simple. The direct TPMS high technology uses multiple receivers near each wheel and can supply information to the driver about each individual tire. However, simplest system will only sign that a tire is low in pressure, the driver must then check all the tires to determine which ones are low pressure.

Vehicle manufacturers typically require a TPMS sensor from a specific original equipment supplier, which can vary from model to model. Using an incorrect sensor will result in an unsuccessful operation of it. Some aftermarket sensors are designed to contain a variety of algorithms (computer programs) that are compatible with multiple vehicle platforms. They must be programmed to communicate with the vehicle using a special programming tool which assigns an ID number to each sensor. New sensors are shipped in storage mode in order to preserve battery life. Depending on the sensor manufacturer, there are a various method used to wake up the sensor to begin its service life.

Some sensors require a 125 kHz transmission signal from a TPMS activation tool. Most sensors allow activation by a tool that services multiple sensors and vehicles. Also exist sensors which require the specific vehicle manufacturers activation tool. Some systems will automatically learn the new sensor ID and its location on the vehicle. On some models, the activation tool may be plugged into the OBD to upload the sensor IDs to the computer. Do not start diagnosis or replacing any parts without understanding how your system operates.

Most direct TPMS use RF ultra-high frequency (UHF) radio signal in one of the unlicensed Industrial, Scientific and Medical (ISM) bands for transmitting the data often around 434 MHz in Europe and 315 MHz in much of the rest of the world. On some systems there is a separate receiver or antenna near each wheel, whilst more commonly have one receiver, which receives data from all of the wheels on the vehicle. Commonly this receiver is additionally used for remote keyless entry system (RKE).

In direct TPMS sensor is also integrated at low frequency (LF) operating 125 kHz short range receiver, sometimes named as Initiator. It works as near field (magnetic induction) communication system in smart phone or immobilizer.

LF module may work without a battery. As a result, it may do a lot of useful works without using TPMS battery power. The LF interface allows a bidirectional communication with the other TPMS modules. LF module can save TPMS battery power by activating (wake up) the TPMS to measure and transmit data, while other time TPMS may sleep. LF module can help identify the location of tire that transmits the data. The aim of the LF also is for the other various practical reasons: register (activate) of a unique ID number (wheel localization feature), for diagnosis, install or update configuration data [6.67]. Additional instrument may be used for this purpose.

Direct TPMS have installed pressure sensors on each wheel. The sensors measure the tire pressure in each tire and report it to the vehicle's computer. They measure and may alert temperature of the tires too. Sensors are powered by batteries which limit their useful life. Most mounted on the inside of the rim, they are no longer easily accessible for battery change and the RF link must overcome the attenuating effects of the tire which increases the energy need.

The discharged battery then meaning that the whole sensor will have to be replaced and the exchange being possible only with the tires dismounted. The lifetime of the battery becomes a crucial parameter. To save energy and prolong battery life, many TPMS sensors do not transmit information when not rotating. All sensors have individual identification numbers (ID) that exclude influence of the information of other cars.

When the direct TPMS system is installed at the factory the unique ID numbers are registered in car computer. This process requires the activation of the direct TPMS sensor using LF radio and the capture of the UHF data transmitted. After changing the sensor, the registration is required. TPMS Service or Reset tools are used. These tools can also be used to check the direct TPMS for faults prior to disassembly. If a TPMS sensor or its position on the car is changed without re-registering the IDs, then the TPMS warning light will turn on and stay on until the ID's are re-registered. More about tire ID, its registration and re-registration read in your car Owner's Manual. It is recommended to visit an official dealer for ID registration.

The spare wheel is not equipped with the TPMS sensor. When a spare tire is mounted, the car TPMS will not function.

When the direct TPMS warning light comes on, either one of the tires is under a fault. The system does not necessarily indicate which tire has a problem. Check the pressure of all of the tires with a gauge and determine the cause of pressure loss and add air, may be requires replace wheel or call technical assistance.

The influence of internal air temperature is important on the pressure of tires on cars. Therefore, it is necessary to measure (it is a car computer work) not only the pressure, but also the temperature in the tire in order correctly do decisions and to inform driver.

In most current TPMS is used a small electronic block which is rugged enough to be mounted inside a tire. It measures the pressure using a microelectromechanical system (MEMS) pressure sensor. Data and other information are transmitted to car computer. Other information includes an ID, also, temperature, acceleration and the status of the complete tire pressure monitoring system. The various combinations are used to avoid interference signals from different tires. For example, can be organized random generated transmission from different wheels.

At present in TPMS two main sensors Capacitive and Piezoresistive are mostly used [6.68-6.70]. The third Surface acoustic waves (SAW) TPMS is not widely applied [6.71, 672]. It is more under investigations. It does not require battery. Below we shortly discuss that sensors. The part of parameters of few sensors are presented in Table 6.8 [6.68-6.72].

Table 6.8. Parameters of three Capacitive, Piezoresistive and SAW type TPMS sensors.

Manufacturer	NXP Freescale	Infineon	Stack
Model	FXTH870x	SP37	ST93xx
Operation	Capacitive	Piezoresistive	SAW
A/D (analog/digital)	8 bits	8, 16 bits	No need
Technology	Si CMOS	MEMS	Piezoelectric
Pressure	0.99-4.44 atm	0.99-4.44 atm	0-3 atm
Accuracy	0.07 atm	0.07 atm	0.034 atm
Accelerometer	Yes	Yes	No need
Temperature sensor	Yes	Yes	Yes
RF	Yes	Yes	Yes
Configuration	LF*	LF*	RS232/USB
Battery	Yes	Yes	No need
Power management/ Voltage sensor	Yes	Yes	No need
* - LF is low frequency, see text and Fig. 6.7.			

The block diagram of monitoring & control TPMS, for instance, SP37 is presented in Fig. 6.7 [6.70, 6.73]. The SP37 measures pressure, radial acceleration, temperature and supply voltage. The pressure range is from 100 up to 450 kPa (0.99 up to 4.44 atm). The Infineon TPMS SP37, is a highly integrated, low consumption energy TPMS sensor, which embeds measurement of pressure and radial acceleration with a low-power microcontroller. A LF receiver and an RF transmitter in a system package are integrated as well. This high integration of the functions allows to build a complete system and, thus, enable system' cost savings. The SP37 inherits its MEMS technology from the acquisition of the Norwegian Sensonor in 2003. The similar structure is TPMS FXTH870x, which history begins from Motorola, was developed in Freescale and at present in NXP.

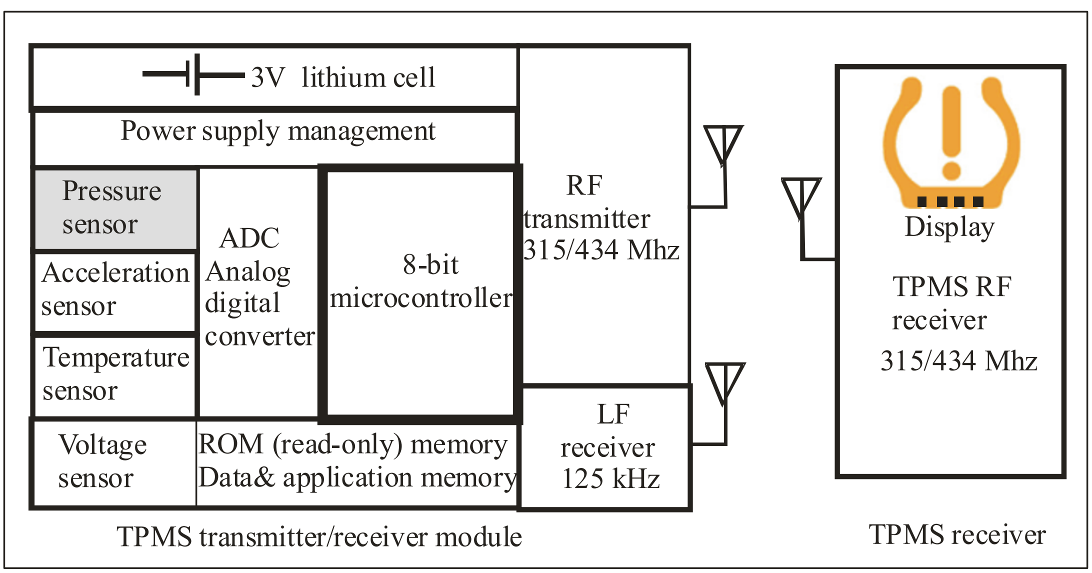


Fig. 6.7. Block diagram of monitoring & control TPMS.

6.8.2 Micro electro-mechanical systems (MEMS) pressure sensors

Micro electro-mechanical systems pressure sensors, both capacitive and piezoresistive, have been among the foremost successful devices developed within the MEMS field. Compared with their piezoresistive counterparts, capacitive pressure sensors have several distinct advantages: higher sensitivity, greater long-term stability, reduced temperature dependence and lower power consumption. The disadvantage of capacitive sensors is that they exhibit high response nonlinearity.

The basic capacitive pressure sensor consists of two plates with a vacuum between them. The pressure sensor operation is extremely simple. The two plates capacity is equal

$$C = (\varepsilon_0 \varepsilon_r A)/d, \qquad (6.10)$$

where ε_0 is vacuum permittivity (electric constant), which equals $\varepsilon_0=8.854\times10^{-12}$ F/m (Farad per meter). ε_r is the relative permittivity (dimensionless) of the dielectric material in between the capacitor electrodes, for vacuum $\varepsilon_r=1$. Letter A is that the area of overlap between the electrodes in meters squared (m^2), and d is that the separation between the electrodes in meters (m). If a pressure is applied on top diaphragm, as shown in Fig. 6.8, it changes distance d between the plates and also changes capacity: higher pressure, shorter distance and higher capacity [6.74, 6.75]. With electronic network we will detect changes of capacity and measure the air pressure within the tire. Measuring pressure is absolute because inside sensor is vacuum.

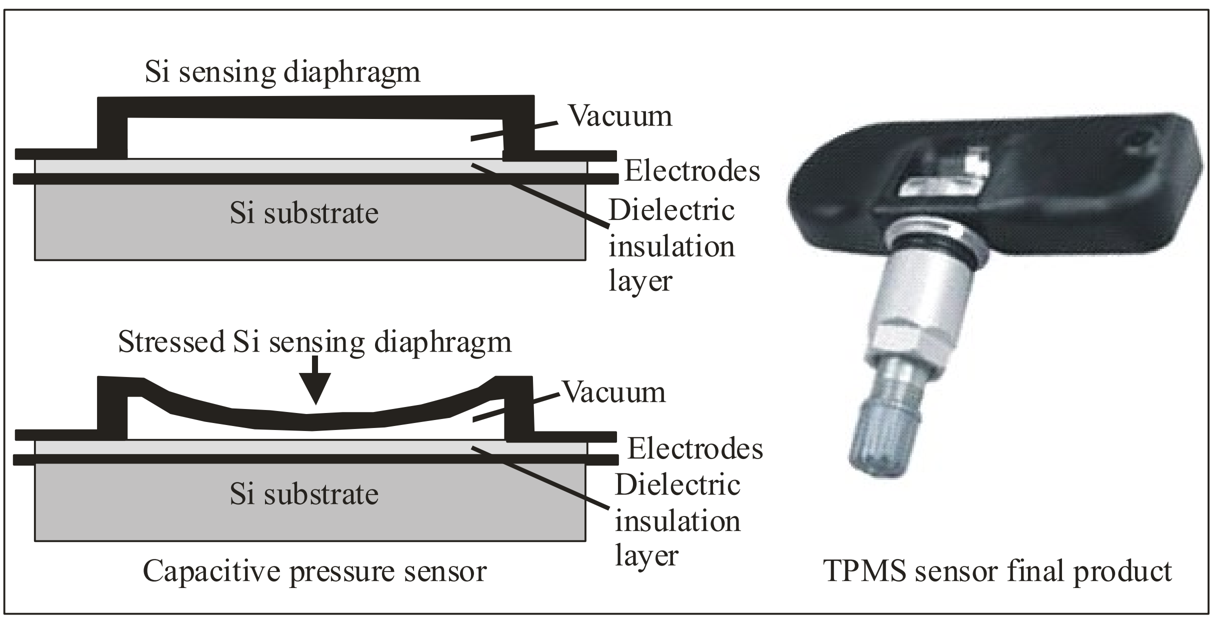


Fig. 6.8. Schematic diagram of the capacitive pressure sensor (left) and TPMS sensor final product. In touch mode, the pressure sensor is without dielectric insulation layer in diaphragm region, however, in this Fig. (left) this layer is shown.

For instance, capacity pressure sensor design parameters are: diaphragm radius is 110 μm, diaphragm thickness is 2.5 μm, cavity height (distance between capacitor plates) is 1.5 μm (depends on pressure), dielectric layer thickness is about 50 nm. Sensor sensitivity is 0.092 pF/psi=1.33 pF/bar=1.35 pF/atm [6.74].

Below in this section we'll discuss piezoresistive detection of tire pressure in two methods. Piezoresistive measure pressure is extremely similar to capacitive.

First method. On silicon membrane doped resistor-area is formed, which resistance depends on deformation. For instance, it's known that good piezoresistive sensitivity has p-type silicon in some crystallographic directions. Measure the changes of resistance you detect change in pressure. Electric bridge method is employed for higher sensitivity in pressure measurement. Four piezoresistors are placed on a membrane forming a Wheatstone bridge circuit [6.75-6.77].

Second method. Previously discussed capacitive pressure sensor usually speaking works in normal mode. However, there exists a similar sensor working in touch mode. In this sensor dielectric insulation layer is absent, for instance, see Fig. 6.8. in which is shown dielectric insulation layer for previous sensor. The sensor operates at the instants of two electrodes coming into contact. When two electrodes are in touch mode, the contact area increases, when external pressure increases or reversely. In this case changes of contact area determine the changes of electric resistance of the contact. It works similarly as a rheostat.

Silicon technology is extremely useful, because may be produced various as temperature, acceleration, voltage and other sensors in parallel.

6.8.3 Surface Acoustic Waves (SAW) TPMS

The understanding Surface Acoustic Waves (SAW) TPMS from first view is more complex. Firstly, it requires piezoelectric material and, secondly, the conversion of electromagnetic waves (electrical signal) into acoustic waves, and for detection of the acoustic waves as electromagnetic waves (electrical signal) needs an interdigital transducer as well.

An interdigital transducer (IDT) is a device that consists of two interlocking comb-shaped arrays of metallic electrodes (it reminds outdoor TV antenna). These metallic electrodes (for instance, aluminium) are deposited on the surface of a piezoelectric substrate, like as quartz or lithium niobate, to make a periodic structure. For sensors two interdigital transducers are required: one for excitation (input), another for transmission (output). However, working in reflection mode, can be used only one IDT [6.78-6.81]. In this case the reflectors on piezoelectric plate is required, which consist of narrow metal bars (See Fig. 6.9). Distances between bars and width of the bars for IDT and reflector is in micrometric range.

Surface acoustic waves is far slower than electromagnetic waves in free space. Quartz SAW velocity is v=3160 m/s, whereas light speed is about 3×10^8 m/s. For frequency f=434 MHz we calculate SAW wavelength is equal $\lambda=v/f=3160/464\times10^6 = 7$ μm. Thus, for IDT the required period is going to be $\lambda/2 = 3.5$ μm. Half period is metalized and half is free surface. The period is dividing in two parts and that we get width 1.75 μm of every metalized and free surface layer.

The signal delay time is of the order of microseconds, $\Delta t = 2d/v = 0.01/3160 = 3$ μs, d (in m) is distance between IDT and reflectors. It non problematic to measure this time duration. The appliance of the measuring pressure produces the diaphragm strains and, hence, the variation within the SAW velocity and changes delay time of the reflected pulse or resonating frequency of SAW device. More problems arising to measure the changes in delay time Δt with pressure, it is smaller quantity to be measured. For more sensitivity SAW resonators are used. In this case central frequency shift is measured.

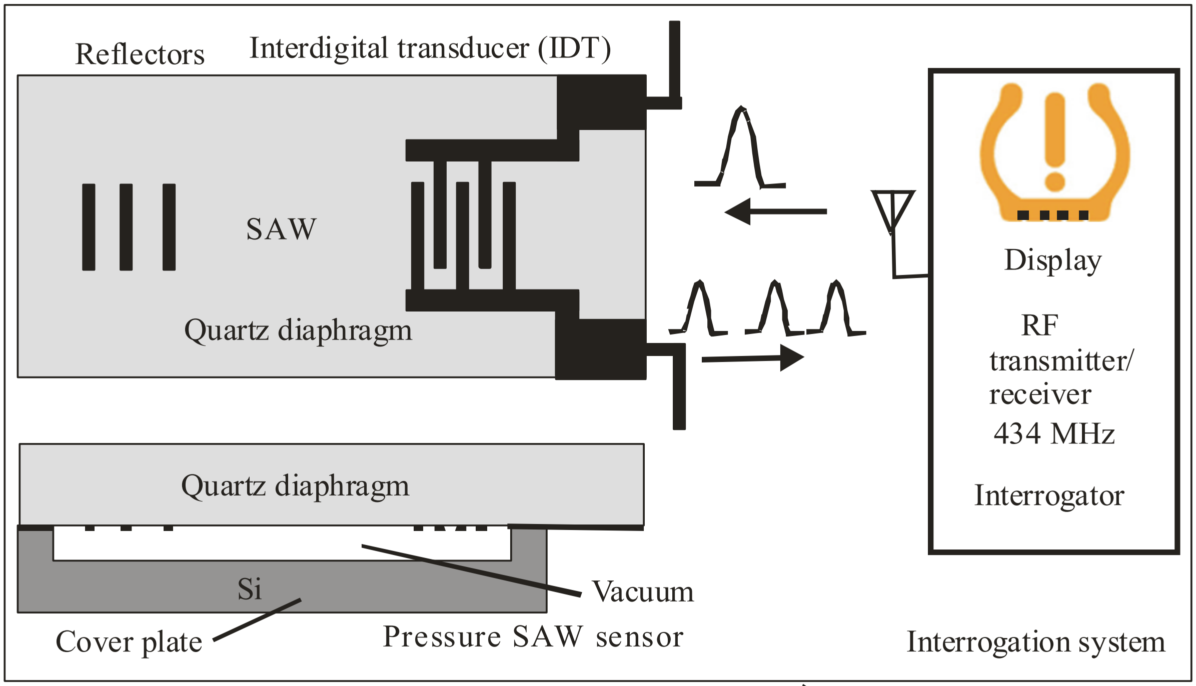


Fig. 6.9. The SAW-based pressure sensor (left) and interrogation system (right). Sensor operates as delay line.

On this occasion we shortly overview this and other SAW sensors as well. The phenomena of pressure, strain, torque, temperature, and mass can be sensed by the basic device, consisting of two IDTs separated by some distance on the surface of a piezoelectric substrate. These phenomena can all cause a change in length along the surface of the device. A change in length will affect both the spacing between the interdigitated electrodes and the spacing between IDTs affecting the delay. This can be sensed as a phase-shift, frequency-shift, or time-delay in the output electrical signal. For measurement of pressure reference pressure (or vacuum) is required. SAW sensor will be placed on Si vacuum camera (cover plate) as in previous cases as shown in Fig 6.9.

SAW Sensors are passive (no power required), wireless, low cost, rugged, and extremely small and lightweight, making them well suited for measuring pressure, temperature & torque (strain) in moving objects (e.g. tires, drive shafts etc.). These characteristics offer significant advantages over technologies such as capacitive and piezoresistive sensors, which require operating power and additional electronics to make a wireless connection.

A company Stack TPMS has developed a SAW-based tire pressure monitoring system (See Table 6.8), which is supposed to be available on the market for motorsport applications [6.72]. Claimed that their SAW tire pressure sensor has 1m of reading range.

A SAW measurement system is capable of wirelessly monitoring applications using measurement unit named interrogator, which transmit and receive RF waves to and from sensor. One of the problems associated with a SAW sensing system is its short transmission range. Therefore, the transmitting and receiving antennas of the read-out system have to be mounted close to the SAW sensors. The greatest advantage of the system that SAW sensors do not need batteries. Interrogator (transmitter/receiver) uses power from the vehicle battery.

6.9 Torque sensors

The torque is a measure of the forces that cause an object to rotate. Reaction torque is the force acting on the object that's not free to rotate. An example of the reaction torque is a screwdriver applying torque to a rusted screw. Product of torque and rotation angle per time unit determine power, and power determines system efficiencies. Torque measurements are very important and used for process control. For instance, a car gear box uses a low gear predetermined maximum torque to initiate start a car.

6.9.1 Introduction to torque sensors

The term torque in rotation motion is extremely important parameter. In practice it is more complicated for understanding. However, to deepen the understanding of the car, we want to know what that mean. A torque is an influence which tends to change the rotational motion of an object. More rigorously, torque, or moment of force is the rotational equivalent of the force in linear motion. Just as a linear force is a push or a pull, a torque can be thought of as a twist to an object. The symbol for torque or moment of force we denote by letter M (may be used other symbols τ, T, so on). Torque is a vectoral size. For simplicity, we will assume that the action of the force is perpendicular to the radius vector of rotation and then we can express equations in scalar form

$$M = F \times r, \tag{6.11}$$

where F is force, which measures in N (Newtons), r is radius, which measures in m (meters) and torque M is (moment of force), which measures in Nm (Newton meter).

In your car manual or brochure are presented two parameters: Power P in kW and torque M in Nm (non-SI units also may be used). What parameter is more important and what relation is between them. In case of sport cars, we are more speaking about power, however in case of heavy vehicles we are more speaking about torque. The power in linear motion is expressed

$$P = F \times v, \tag{6.12}$$

where v is traveling speed in m/s (meters per second). The power of rotational motion can be expressed by a formula

$$P = M \times \omega, \tag{6.13}$$

where ω is the angular speed in radians per second, which is equal $\omega = 2\pi f/60$, if f is revolutions per minute (rpm). If we look, we get simple relation between power and torque

$$P = M \times (2\pi f/60). \tag{6.14}$$

If your engine has M = 250 Nm at f = 4000 rpm, you can calculate that equivalent power is about $P \approx 100$ kW. If you know power, you can simply calculate torque. If you compare values presented in manual may arise a problem, because manufacturer presents power and torque at different engine rotation speeds. Further text will show the importance of torque in the car.

Most commercial vehicles and tractors have diesel engines. Diesel engines generate more torque at lower rotation speed. It means a simple start from the rest and traveling in the mountains. Horsepower is important because it allows a car to move faster on the highway and at high rpm.

The first thing to do is to move the car from the rest. This needs a high force or high torque. We will achieve this by transforming the torque. This is often done by the gearbox. Reducing the gearbox revolutions, we increase the torque while moving the car easily from rest.

Another thing, like the four-wheel drive system, needs to redistribute the power between the front and rear wheels, even between the individual wheels. This requires a flexible and controllable system. The power in each spot is difficult to measure, however it is possible using the torque control. Such sensors may be mounted on the axles, as well as on the motor shaft and others.

The Torque sensor may be adapted for transmission, axle, differential and engine applications. For four-wheel drive systems, a torque sensor is useful to control torque distribution between front and rear axles, thereby improving traction control, vehicle stability dynamic algorithms and braking dynamics. Torque sensors can be used to directly measure engines torque as well. Direct torque measurements can improve fuel economy by providing closed loop feedback to the engine controller. It helps to control how do ignition and fuel supply system work. Torque sensors are also used to measure the steering wheel torque of the electric power steering.

A torque sensor, also named torque transducer or torque meter, is a device for measuring the torque on a rotating system, such as an engine, crankshaft, gearbox, transmission and other rotating parts. Static torque is relatively easy to measure. However, rotating systems torque is not simply to measure. It requires transfer of some effects as mechanic to electric or magnetic from the shaft being measured to a nonrotating static system.

One way is measure stress in shaft. Other method is detecting torque by measuring the angular displacement between a shaft's two ends or at two places. A magnetoelastic torque sensor also can be used to measure the torque applied to a shaft.

A more recent development is the use of SAW devices attached to the shaft. The strain on these tiny devices as the shaft flexes can be read remotely and output without the need for attached electronics on the shaft.

Possible wireless dynamic torque sensors [6.82-6.85] are presented in Table 6.9.

Table 6.9. Wireless dynamic torque measurement sensors.

Method	Torque conversion	Method detection	Detection/transmission
Torsional shear stress	Strain gage (gauge)	Wheatstone bridge (piezo resistors)	Inductive coupling or RF receiver
Torsional deflection (For Electric power steering systems)	Mechanical Difference in angle between two parts of the shaft	Magnetic	Hall detectors
			Magnetoresistors (NiCo or NiFe alloys)
		Magnetic induction	Inductivity, toothed rings, coils, oscillating current
		Optical, Discs with barcodes or apertures (spokes)	Photo detectors
Magnetoelastic	NiFe alloy (Permalloy), CoFe alloy (Permendur), 2V-Permandur (2% V). May be used remnant (residual) magnetic field	Coils	Fluxgates
		Hall effect	Hall detectors
Surface acoustic waves (SAW)	Piezoelectric effect, Interdigital transducer. SAW delay line or resonator. Quartz plate	RF (transmitter-receiver)	Interrogator
Note: The measurement scale of various magnetic field (magnetic induction) sensors is about: For Fluxgate is in the range (10^{-4} - 0.5) mT; for Magnetoresistance is in the range (10^{-3} - 5) mT; for Hall effect is in the range (0.1 - 3×10^{4}) mT. [6.86]. For comparison, the Earth magnetic field (magnetic induction) is in the range (0.025 - 0.065) mT.			

A transmission shaft, subjected to an external torque, is shown in Fig.6.10 (left). The torque induces internal stresses in the shaft which resist to the action of twist. The internal stresses are called torsional shear stresses. In the shaft occurs an excess of the rotation angle of one end of the shaft relative to the other.

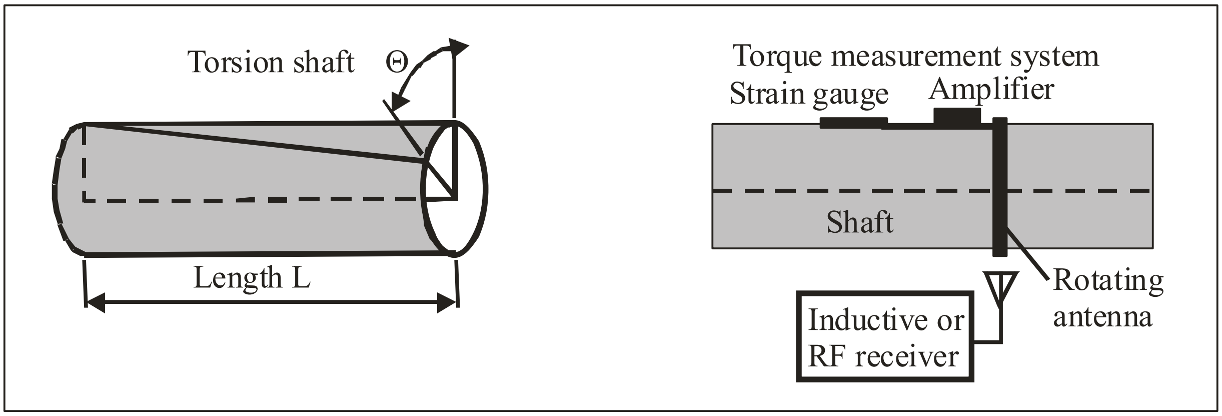


Fig. 6.10. The angular deflection of a torsion shaft (left) and torque measurement schema (right).

When a shaft is subjected to a torque or twisting a shearing stress is produced in the shaft. The shear stress varies from zero on the axis to a maximum at the outside surface of the shaft. The shear stress in a solid circular shaft in a given position can be expressed as

$$\tau = (M \times r)/J, \qquad (6.15)$$

where τ is shear stress in N/m^2, M is applied torque, r is radius of the shaft in m, J is the polar moment of inertia (for solid circular shaft $J=\pi r^4/2$) of cross-section with respect to the axis of rotation in m^4. In addition, the angular deflection of a torsion shaft can be expressed as

$$\theta = (L \times M)/(J \times G), \qquad (6.16)$$

where θ is the angle in radians (for small angle $\tan(\theta) \approx \theta$). L is the length of shaft or the distance between measurement points. G is the shear modulus (modulus of rigidity) in N/m^2. From equations 6.15 and 6.16 we can determine torque from measurements of the stress or angular deflection, which may be obtained as displacement [6.87, 6.88].

6.9.2 Torsional shear stress torque sensor

Strain gauges are the foremost common way to measure the torque applied to a shaft. A strain gauge (sometimes referred to as a strain gage) is a sensor whose resistance varies with applied force. It converts force, pressure, tension, weight into a change of electrical resistance which may then be measured. When external forces are applied to a stationary object, the result are stress and strain [6.89]. When measuring the dynamic torque on a rotating shaft, slip rings, wireless telemetry and/or rotary transformers must be used to power the strain gauge bridge and receive the signal.

Company Manner Sensortelemetrie developed contactless Manner Flex torque and other parameters measurement technology. It allows the measurement of torque, force, temperature etc. in very compact and simple installation conditions [6.90-6.92]. The rotor-antenna, sensor, measured signal amplifier and casing can be accommodated within a height of just a few millimetres. This avoids any annoying or complicated modifications to allow the measuring technology to be housed. Since the load of the telemetry is little, the system is not influenced by its own behaviour and therefore problem of its balancing is eliminated. Flex telemetry is very robust and is suitable to be used in very tough environments.

Torque acquisition on shaft is realized by strain gauge. Normally two double strain gauges (4 resistors) are connected to a Wheatstone bridge for optimum compensation of the temperature drift. The output voltage of the strain gauge bridge is proportional to the torque M and, therefore, the amplified output voltage is also proportional to the torque M. Measurement schema is shown in Fig. 6.10 (right). Between stator and rotor systems is used inductive coupling system, similar to Near field communication NFC system. External induced signal is used as power supply for sensor, for measured signal amplifier and for RF transmitter too. RF signals of coupling system, commonly, 13.56, also 6.78 or 3.38 MHz are used. However, wheel torque meter module transmits RF information at 433/869 MHz frequency, but in this case, battery is required, as in the direct TPMS.

6.9.3 Magnetic torsional deflection (displacement) torque sensor

One of important application in cars is electric power steering (EPS). A typical EPS steering application uses a bidirectional brushless motor, also sensors and electronic controller to supply steering assist. Sensors located within the steering column measure two primary driver inputs - torque (steering effort) and steering wheel position. There are differing types of electronic torque sensors [3.43, 6.1, 6.93], and they are often classified as of contact and non-contact types.

Torque can be determined by measuring the difference in angle between two parts of the shaft caused by the twisting. This shift could also be converted to a linear movement and then measured by linear position detectors as Hall, magnetoresistors. Magnetic induction or optical methods can also be used [6.94-6.96]. Since the movements are often relatively little, mechanical amplifiers (higher diameter discs) may be used to enlarge the deformations of the shaft. For the modern EPS the active torque measuring range is of approximately 10 Nm. The typical stiffness of a torsion rod in modern EPS systems is between 2 and 2.5 Nm per degree of torsion angle (2-2.5) Nm/deg, where deg is angle in degree). The highest torsion is limited by a mechanical entrainment to ±5 deg for the protection of the torsion bar.

A contactless sensor uses (see Fig. 6.11, left) a magnetic rotor with alternating pole pieces which is attached to the torsion bar. Hall-type sensors monitor the twist of the torsion bar by measuring the change in magnetic flux generated by its position to the vanes located on the sensor stator rings. When the rotor moves, a change in magnetic flux will produce a signal. The signal is measured and processed with an analog sensing integrated circuit (ASIC) chip. It sends the information to the steering processing-controlling system [6.94].

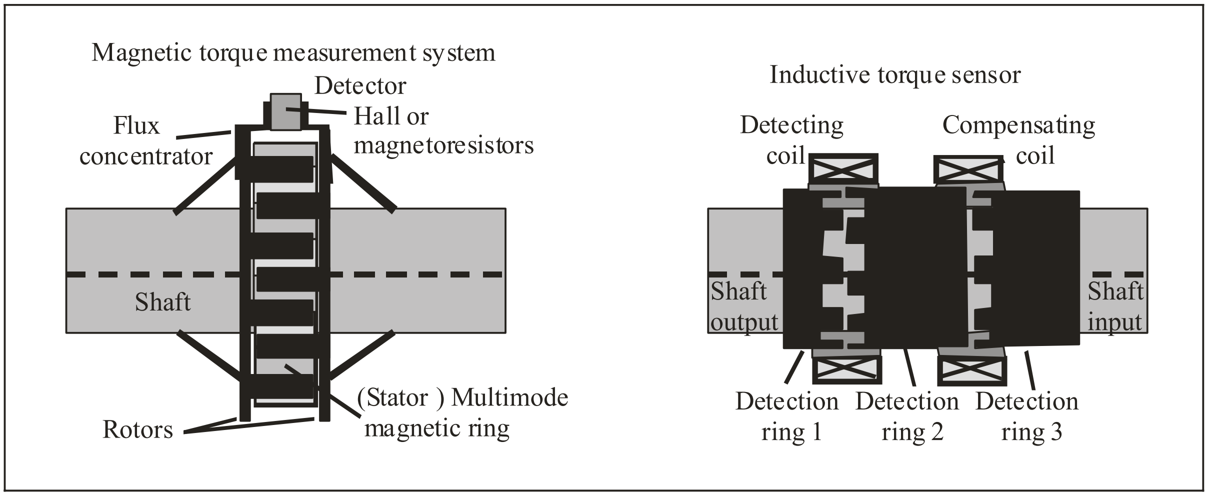


Fig. 6.11. Magnetic torsional deflection torque sensor (left). Inductive torque sensor (right).

Similar system uses Bosch [4.47, 6.97]. In this system are used magnetoresistance detectors. Magnetoresistance is the tendency of a material to change the value of its electrical resistance in an externally-applied magnetic field. There are a variety of effects of the resistance changing which are called magnetoresistance.

In this case the magnetic detector has multiple magnetoresistance (MR) elements on an insulating substrate, like glass. The MR elements could also be made as thin film permalloy (NiFe) or nickel-cobalt alloy (NiCo) [6.85].

The detector sits on the steering pinion. A pole wheel is fitted on the input shaft, which is connected to the steering pinion by means of the torsion bar. When the driver applies torque to the steering wheel, the torsion bar is rotated and, in turn, the magnet rotates relative to the sensor. The sensor consists of magnetoresistive elements whose resistance changes as the magnetic field direction changes. The torque sensor's measuring range covers 10 Nm. In torque sensor is often integrated position sensor, which allows the rotation speed of steering wheel to be calculated.

6.9.4 Magnetic induction torque sensor

Magnetic induction torque sensor in steering systems is presented in Fig. 6.11 (right). The sensor is predicated for a system of coils which is driven by an oscillator [3.43, 6.92, 6.98]. The voltage induced in detecting coil changes as a function of the torsion angle of the torsion rod. This coil is arranged over two soft magnetic rings. Each ring is mechanically connected to a different end of the torsion rod. Both rings are toothed along their perimeters. The effective air gap between both rings changes as a function of the torque. This changes the impedance (AC resistance) of the detecting coil. Impedance, measured in Ohms, is the effective resistance to current flow in an AC (alternating current) circuit containing resistance and in this case inductance type. The compensating coil is arranged over a magnetic circle that is independent of the torsion angle and serves as a reference. Both the detecting and compensating coils make up the bridge. Only the changes within the impedance of the detecting and compensating coils are taken as voltage signals. The high-frequency portion is removed by the detection circuit, and only the torque useful signal is detected and amplified.

6.9.5 Optical torque systems

Optical torque sensors use discs that have barcodes or apertures [6.1, 6.99, 6.100]. We'll deliver one of them. Optical sensors contain a light-emitting and a photosensitive component. A standard configuration of optical sensors are encoders, often utilized in automation for high-precision positioning systems. As an example, an optical torque sensor mounted on a torsion bar which may be a part of the steering column. The discs with barcodes on its surface are attached to every end of the torsion bar. A light source within the sensor module illuminates the surface of the coded discs, partially reflecting the light through a lens onto an optoelectronic detector. The light intensity on the sensitive surface of the optical detector, which is an array of photodiodes, depends on the code of the discs. The intensity distribution over the photodiodes allows the optoelectronic detector to calculate the absolute angular position and therefore the angular displacement of the steering shaft.

Fig. 6.12 (left) shows the optical torque sensor concept. The contactless torque and speed measurement system consisting of two barcode tape directly glued around the shaft with two optical sensors mounted on non-rotating supports. This technique operates entirely contact-free and torque measurement does not requires complicated design. The barcode tapes feature an equal number of equidistant black and white stripes and are glued round the shaft. As the shaft rotates, each optical sensor, mounted on a non-rotating component, generates a pulse train signal proportional to the light intensity reflected by the barcode tape stripes. When a torque M is applied to the shaft, the relative rotation of the ends of the shaft section creates twist angle, and lead to a time shift Δt between the two pulse train signals. With similar operation of the optical torque sensors system, it is possible to measure the angular displacement and absolute angular position of the steering wheel, and also determine the torque applied to the shaft [6.1].

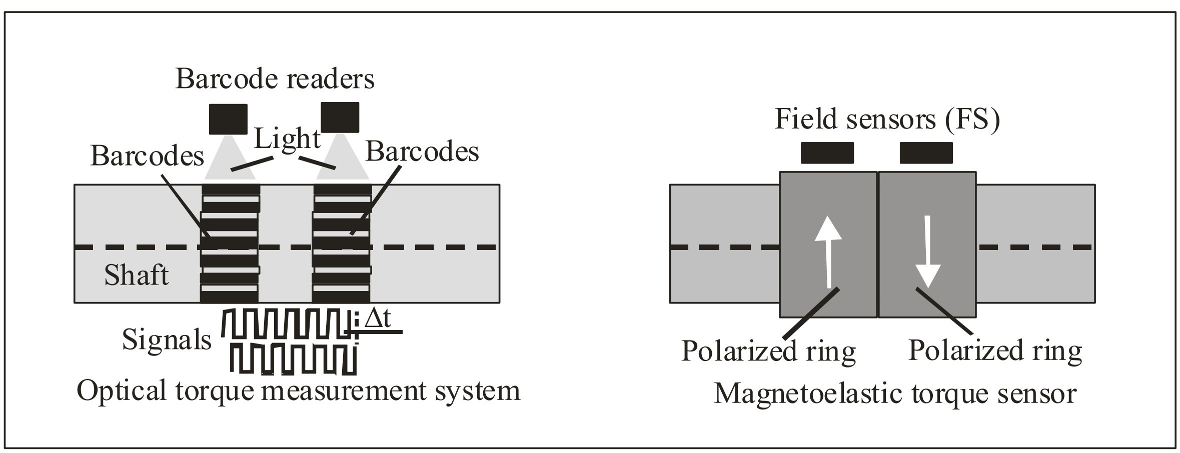


Fig. 6.12. Optical torque measurement system (left) and magnetoelastic torque sensor (right).

The optical measuring principle means the sensors are very insensitive against electro-magnetic disturbances. Code disks and optical structures help to achieve very high resolution. However, due to the very harsh conditions, and due to their sensitivity to dirt, and due to limited mechanical load capacity, these sensors can only be utilized in limited circumstances. Optical torque sensors within the cars are used for EPS systems (clean environment) at the moment.

6.9.6 Magnetoelastic torque sensors

Various variations of magnetoelastic torque sensors (transducers) can be realized in automotive applications using different detection systems [4.47, 3.43, 6.101-6.103].

Under the influence of a magnetic field, ferromagnetic materials change their length in the direction of the field (magnetostriction effect). Here, depending on the same field direction, the length can either increase (positive magnetostriction) or decrease (negative magnetostriction) depending on the material. The inversion of this effect, the change in magnetic characteristics under tensile and compressive stresses (elongation and compression), is known as the magnetoelastic effect.

For these types of torque sensors, a shaft with a series of permanent magnetic domains or a shaft with attached rings made of that material can be used. The magnetic characteristics of those domains will vary according to the applied torque, and thus can be measured using non-contact sensors.

More used transducer construction in which a single circularly polarized ring is replaced by two oppositely polarized rings each having half the axial length of the single ring. That system has substantially reduced the effects of ambient magnetic fields on measured torque.

For magnetoelastic torque sensor measuring element can be used fluxgate, magneto-resistor, or Hall effect detector. A fluxgate magnetometer may be a device that measures the intensity and orientation of magnetic lines of flux. A fluxgate magnetometer consists of a soft-iron core with two coils wrapped around it: a drive coil and a sense coil. An alternating voltage drives the core continuously through a complete hysteresis cycle, from saturation in one direction to saturation within the other. The sense coil measures the flux.

The torque measuring elements are fixed on a stationary construction near the shaft. The coils utilized in bridge configuration and signal output are often used analogue or digital. The principal magnetoelastic torque sensor schema shown in Fig. 6.12 (right). For fluxgate torque detection system, the key point is to make a magnetically active area within a base shaft containing magnetoelastic properties. As torque is applied to the shaft, proportional stresses are imparted. This leads to measurable magnetic field change that correlates with the applied torque. This effect is related with the inverse magnetostrictive effect. It also referred to as magnetoelastic effect or Villari effect.

6.9.7 Surface Acoustic Waves (SAW) torque sensors

The SAW device is rigidly mounted to a flat spot on a shaft, and therefore shaft experiences a torque. This torque will stress the sensor and turn it into a wireless passive lightweight torque sensor [6.104-6.107]. For practical applications, two SAW torque sensors are utilized in such a way that their centre lines are at right angles (see Fig.6.13). For the measurement torque (stress) two sensors of either the SAW resonators or delay lines are glued onto the shaft at 45-degree angles. We consider SAW resonator type torque measurement system. Common principle of operation of the SAW delay line was discussed in paragraph 6.8.3 and operation schema was shown in Fig. 6.9. The resonator type measurement system is more sensitive. A SAW resonator is basically consisting of Fabry-Perot resonator with two mirrors on the ends of the piezoelectric substrate. Reflecting gratings can be used as Bragg mirrors of SAW waves. Reflecting grating consists of regular array of strips. The strips are often shorted metal electrodes (see Fig.6.13, top position). In this system, when one sensor is in compression, the other sensor is in tension. Since both sensors are exposed to the same temperature, the difference of the two signals minimizes any temperature drift effects. Resonators operated with an alternating voltage of suitable frequency; the piezoelectric substrate generates a mechanical vibration which spreads out along the material surface. External forces, from strain and compression lead to a change of the resonator frequency. The frequency change is therefore a direct measure of the applied torque.

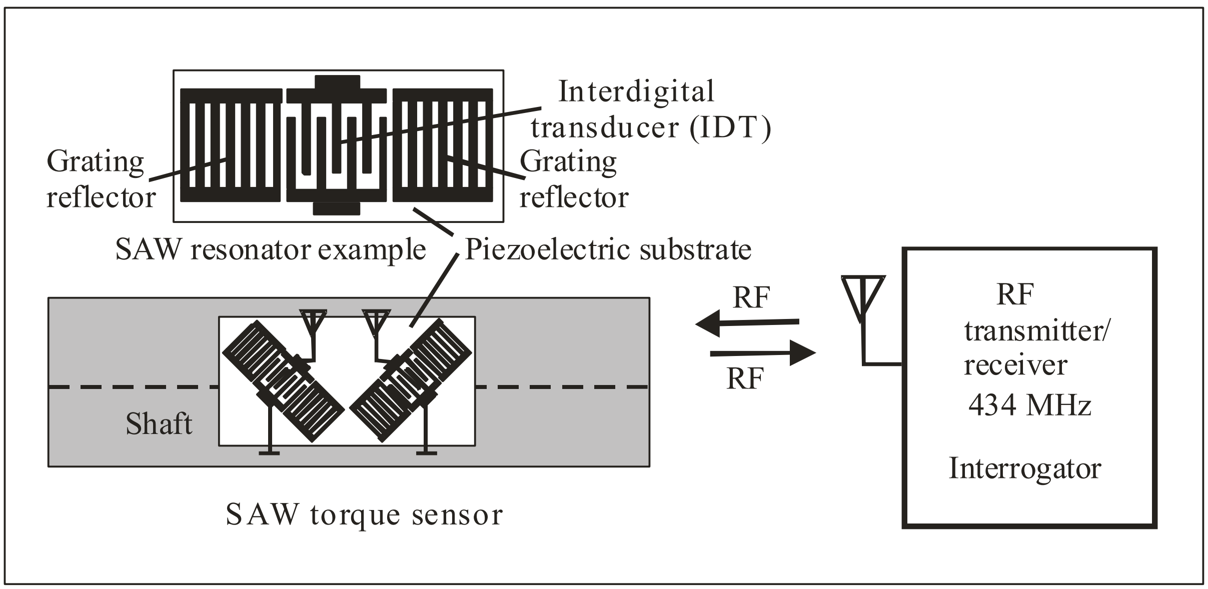


Fig. 6.13. The SAW-based torque sensor (left) and interrogation system (right). Sensor operates as resonator. On the top shown SAW resonator example.

The electromagnetic waves are often sent to the SAW device both wired or wireless. It does not need an auxiliary power supply which makes it useful in wireless applications, only the energy within the signal is employed. When used wireless, an antenna must be connected to the SAW chip to pick up the signal and then transfer it back. For two-port chip two antennas are needed. The ability to work wirelessly and without power supply makes it suitable for rotating shafts. The sensor operation principle is analogous as in the case of SAW TPMS. Sensing elements are SAW interdigital transducers and resonators fabricated on a one quartz substrate or another piezoelectric material. For signal transmission and receiving RF 430-437 MHz interrogator is employed.

6.9.8 Torque sensors for the modern car: Measuring ranges

The rotating mechanisms output torque could be increased by multiplying the torque by the gear ratio. While in many applications gear reduction reduces speed and increases torque (for instance, first gear in a car), in other cases gear reduction is used to increase speed (for instance, fifth gear in a car) but reduces torque.

We shortly overview what measurement range for torque sensors within the car drivetrain are often used.

We calculate the torque for few cases in powertrain and show how changes torque changing gears in transmission. The energy (power) conservation law will be used. Energy losses were not taken under consideration. Formulas see in paragraph 6.9.1 (Eqs. 6.11-6.14).

In paragraph 6.9.1 was presented car engine with parameters: Torque M = 250 Nm at 4000 rpm and power P = 100 kW. That parameters are used below.

If the car has a five-speed manual transmission, fourth gear transmits 1:1 (approximate value) rotations. However, wheels rotate 4 times slower, at 1000 rpm, when engine rotates at 4000 rpm. Speed additionally is reduced within the powertrain. With the same power we get 4 times higher torque, which increases to M = 1000 Nm.

When you start driving, you shift 1 (first) gear, accordingly the wheel speed slows down in addition 4 times. Wheels rotation speed in summary reduces 16 times with comparison engine rotation. It means that at the same power wheels torque increases and become equal $M = 250 \times 16 = 4000$ Nm. Increased torque helps the car start to move from the place or from the traffic light, also helps in another hard driving situations. The torque in this case may rise up to 4000 Nm. This example demonstrates that a car torque may be in extremely wide diapason.

Below presented the manufacturer offers samples of torque sensors [6.94-6.97, 6.108]:

High precise power-assisted steering torque sensor 10 Nm;
Torque Measuring at Gear Input Shaft 500 Nm to 2000 Nm;
Torque Measuring at Gear Output Shaft 1000 Nm to 6000 Nm;
High Precise Dynamic Torque Acquisition Pulley Climate Compressor 5 Nm to 200 Nm;
Torque Meter Pulley for Generator 5 Nm to 200 Nm;
High precise dynamic Torque Acquisition on Camshaft 5 Nm to 200 Nm;
High precise dynamic Torque Acquisition Oil Pump 5 Nm to 50 Nm;
High precise Wheel Torque Sensor 500 Nm to 5000 Nm.

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