Any kind of motor vehicle needs a transmission, in order to convert the rotational speed and the torque of its engine into useful power.

Under the term transmission are usually included a start-up device (either clutch or torque converter), variable ratio gearbox, power take-off, used to operate equipment external to the vehicle, and the final drive and differential, which move the wheel; in other words, the term includes the entire kinematic chain connecting wheels to engine.

The function of the transmission is to adapt the available torque from the engine to the needs of the vehicle, which are imposed by the nature of the road, the will of the driver and environmental requirements. The transmission is particularly relevant in determining certain vehicle functions, such as dynamic performance, fuel consumption, emission, drivability and, last but not least, reliability.

Automotive transmissions (we include under this definition cars, industrial vehicles and buses) are characterized, when compared to industrial transmissions, by a higher level of stress. The specific mass (the ratio between the transmission mass and the processed power) of an automotive transmission falls in a range between 0.5 and 1 kg/kW; in an industrial transmission these values are almost doubled. In addition, the number of ratios available to an automotive transmission is definitely higher than that available to an industrial transmission.

Transmission technology can be assumed to be mature; but we do not suggest that there will be no further evolution, particularly in automatic transmissions. As a matter of fact, significant growth of this kind of transmission is expected in the European market. The particular needs of this market have justified the development of a new generation of automated manual transmissions that should not affect vehicle performance negatively and should leave drivers the pleasure of driving manually as they choose.
The continuing development of electronics, both in terms of performance and cost, will have a significant impact on this kind of transmission and will cause rapid development.

We should also not forget that the possible growth of the hybrid vehicle market will stimulate development of particularly sophisticated automatic transmissions.

A last point relevant to transmissions is that their production and development functions are leaving OEMs to become the business of specialists.

This is true for both manual and automatic transmissions. It is particularly important for those who will devote their career to vehicle or component design to develop sound systematic knowledge of this kind of component.

This trend is confirmed by the growing importance in Europe of Getrag, ZF, GM, Fiat Powertrain Technologies and Graziano; the same could be said in the United States for Dana, Eaton, New Venture Gear and Allison, and in Japan for Aisin and JATCO.

Significant growth of automatic transmissions is expected in Europe.

The most widely used type of automatic transmission is the power-shift, with four or more transmission ratios. Many manufacturers have decided to adopt in their cars a continuously variable transmission, with steel belt and variable gouge pulley. Despite some disadvantages for mechanical efficiency, these show superior vehicle performance because of the availability of an infinite number of transmission ratios.

Power-shift transmissions are abandoning pure hydraulic control, in favour of more sophisticated electronic controls that take advantage of the contemporary development of engine control systems, including throttle automation.

On the other hand, many applications with more than five transmission ratios have emerged and the lock-up function of the torque converter is extended to nearly all gears.

Six gear manual transmissions are starting to appear in the market, while the five ratio configuration is standard on all applications; many of these transmissions have received an electro-hydraulic or electro-mechanical actuation system, with the aim of offering customers a similar or superior performance, in comparison with the conventional automatic transmission, without affecting the traditional advantages of lower cost, high efficiency, and the pleasure of driving.

The functions that can be obtained by this kind of transmission include:

- Clutch automation
- Servo assistance in selecting and shifting gears, with positive effects on comfort and actuation speed
- Availability of more ergonomic sequential shifting commands, which can be included on the steering wheel
- Total automation of the choice of transmission ratio and shifting sequence.
Transmission architectures are determined by the kind of traction that is adopted on the vehicle. On the other hand, the choice of traction has a strong impact on vehicle performance, in terms of handling, ride comfort, safety and interior space organization.

The engine can be installed in the front or back of the vehicle; in the first case the traction can be on the front axle, on the rear axle or on both; in the second case the traction can be on the rear or on both axles. Rear wheel driven cars, with longitudinal engine in the front, are usually considered cars with a conventional or traditional layout.

Figure 1 shows all known configurations available for front wheel drive.

Sketch a shows the longitudinal layout, with powertrain on the driving axle; it also shows how some advantage can be obtained for the maximum steering angle of the wheel, with some disadvantage for the front overhang. In this case every transmission ratio can be obtained with a single stage of gears; the rotation axis of the gearbox output shaft must be turned 90 deg with a pair of bevel gears.

Sketch b shows the same previous layout, where the front overhang is shortened by installing the engine over the front axle; in this case an additional shaft and some modification of the oil sump are needed.

Sketch c shows the widely used solution of the transversal power train with engine and transmission in line. Here a single stage transmission is necessary; the output shaft is connected to the differential with a pair of spur gears. Vehicles can be more compact because the front overhang can be shorter; on the other hand the minimum turning radius is negatively affected. The solution is optimum if the engine is not too large.

Finally, sketch d shows a not widely applied solution, where engine and gearbox are transversal and parallel; the gearbox can be in the front behind or beneath the engine. Advantages and disadvantages are mixed, as compared with
the previous case; an additional double stage transmission or a chain transmission is necessary to connect the engine shaft with the gearbox input shaft.

In all these cases the subsystem including engine and transmission is called the power train or transaxle.

Figure 2 shows two possible architectures applied to conventional vehicles; type a is the most widely used, while type b is applied primarily to sports cars, where a more uniform weight distribution is requested. In these cases the gearboxes will be of the double stage type (also known as the countershaft type), where input and output shafts are in line. A bevel gear final drive is also necessary. The front overhang can be reduced; the roominess of the interior is negatively affected by the transmission shaft under the floor.

Also the rear engine lay-out, which is seldom applied, shows two possible architectures, shown in the same figure, with transverse power train arrangement (c) and with longitudinal arrangement (d).

This kind of architecture is now only applied to sports cars, where weight distribution and yaw inertia are more important than interior roominess; the same considerations made in solution a and c of the previous figure apply to solutions c and d.

Architectures applied to commercial vehicles (transportation of people or goods with GVW of less than 4 t\(^1\)) derive from car architecture d of the first figure and a in the second.

Figure 3 shows the architectures that are known for four wheel drive vehicles; configurations a, b and d can be derived from the corresponding lay-outs of the single axle vehicle. These are primarily applied to road vehicles or sport utility vehicles with permanent four wheel drive; solutions a and d are easily designed, because the transfer box can be integrated in the power train. Architecture

\(^1\)This limit value is not coincident with the legislative value (3.5 t), but it is our guess about what is technically feasible for vehicles designed with car technology.
c is applied to vehicles specialized for off-road missions; the transfer gearbox necessary to move the other axle can easily integrate a range-change unit and differential lock.

Considering transmission configurations used in industrial vehicles (transportation of people or goods with GVW of more than 4 t), we must discriminate between trucks and buses, also taking into account that a low price market segment exists, where a bus is strictly derived from a truck.

Architectural configurations for two axle industrial vehicles are similar to those described for conventional drives. The longitudinal power train is installed in the front in a position depending on the type of driver cabin adopted. In the same way, the four wheel drive configuration is similar to that explained in Fig. 3c. In extremely heavy duty applications a second rear driving axle is moved through the first.

Buses, initially derived from trucks, have recently received a dedicated architecture finalized to assure easy passenger access to the vehicle. This access depends upon the height of the door threshold; the desired value for this dimension also differentiates the architecture of urban and suburban buses.

In the first case the easy access must be obtained with no compromise for all doors, and the corridor floor must include no steps or significant ramps, because of the necessity of transporting standing passengers.

Figure 4 shows two different examples; a represents a typical lay-out for urban buses, while b represents a typical lay-out for suburban buses. In the first example, the engine and transmission are installed in the back, under the last row of seats. The corridor floor is low and is conditioned solely by the shape of the axles, which is usually chosen for this purpose; the slope of the corridor is limited, and it is also possible to have doors in the back of the vehicle.

Suburban buses or long range buses, represented in b, show no real need for a lower door threshold; on the contrary, they usually have the baggage

**FIGURE 3.** Transmission architectures applied to four wheel drive; solution c is particularly suitable for off-road vehicles, because an additional range-change unit can be easily integrated into the transfer box.
FIGURE 4. Transmission architectures designed for urban buses (high) and suburban buses (low); the engine shift-back lowers the vehicle floor behind the front door.

compartment under the floor. Passengers seldom stand; the most suitable lay-out has a longitudinal central engine and rear wheel drive.

Independent of transmission configuration, vehicle transmissions include the following components, which are named starting with the engine.

Start-up device

Start-up devices are usually made with a friction clutch, with pedal operation, in some case assisted by an external source of energy (electric, pneumatic or hydraulic); in most automatic gearboxes, start-up devices comprise a hydraulic torque converter with lock-up clutch.

Gearbox

The gearbox is the transmission component that changes transmission ratio; it can be made with conventional or epicycloidal gears. Gear shifts can be performed manually (with only the force of the driver), semi-automatically (with the help of auxiliary energy) or automatically. We can find in the gearbox the following mechanisms, in addition to gears.

- Gear shifting mechanisms: These are classified as internal or external, depending upon whether or not they are contained in the gearbox. The function of gear shifting mechanisms is conditioned by the motion of the power train relative to the vehicle, determined by engine suspensions; these motions should not affect gearshift quality. Gear shifting mechanisms are particularly important in manual transmissions, because they have a large influence on the driver’s feeling of precision and positive response.
**Shifting sleeves and synchronizers**: These are addressed to engaging and disengaging the pair of wheels necessary to obtain the desired transmission ratio.

*Range change units*

These can be considered as additional gearboxes with a limited number of speeds that are inserted on the transmission line after or before the main gearbox; they increase the total number of speeds by a number greater than the added gear pairs; under this category we also include the so-called *splitters*.

*Final drive and differential*

Final drive and differential can be integrated in the gearbox; they further reduce the rotational speed of the wheel. The differential theoretically divides the torque for the two wheels into equal parts and can be free, self-locking or manually-locking.

*Transfer boxes*

Transfer boxes are gearboxes that divide the torque for the axles of an all wheel drive or for vehicles with more than one driving axle.

*Transmissions and joints*

Transmissions and joints connect the several rotating sections of the transmission; in conventional drives they connect the gearbox with the differential. In independent suspensions, they connect the wheel with the differential.

The second part of this volume, dedicated to automotive transmissions, begins with a chapter dedicated to the historical evolution of transmission design.

The principal types of manual transmission applied to cars and industrial vehicles will be described in the following chapter. Schemes and drawings will be used to support this discussion.

Particular attention will be addressed to internal and external shifting mechanisms and to the criteria for their design and evaluation.

The primary start-up devices will be explained and the design and specification rules discussed. For the torque converter only, the methodology for calculating vehicle performance and consumption will be introduced.

In terms of differentials, in addition to design criteria, a short study on the influence of controlled and uncontrolled units on vehicle dynamic behavior will be included.

Various automatic transmissions in use on cars and industrial vehicles will be introduced; the primary control strategies implemented in their control systems will be also discussed.

The book concludes with some complementary ideas on transmission component design and on methods for car and bench testing.