ZF Active Steering in the Steering Column
for Mid-Size and Luxury Cars

ZF Lenksysteme
Steering actively

**ZF Active Steering for increased driving comfort and active safety.**

Modern car manufacturing with its ongoing development makes very high demands on both the overall concept and on systems and single components in the vehicle. ZF Lenksysteme GmbH, a joint venture of Robert Bosch GmbH and ZF Friedrichshafen AG, equips renowned vehicle manufacturers with both high-quality single components and complete steering systems. The ZF Active Steering (AFS = Active Front Steering), which was first introduced in the market in 2003, highlights these features as well and gives an example of modern and innovative developments in automotive technology.

The ZF Active Steering is a steering concept by which the steering angle input of the driver can be increased or decreased. This is accomplished by a complete basis steering system, which has the advantage that it can be mated with either an electric or conventional hydraulic system. An electro-mechanical steering angle actuator is integrated into the system between the steering wheel and the pinion of the steering gear. Through a gearset, this actuator can, if required, add or subtract an additional steering angle in addition to the angle imparted by the driver, or it can generate a steering angle that is independent of the driver. If the particular driving condition does not require an additional angle, the electric motor of the steering actuator remains still. In that instance, there is a direct mechanical connection from the steering wheel to the road wheels, as
is the case on conventional steering gears.

The additional degree of freedom permits continuous and situation-dependent variation of the steering ratio. While conventional steering systems are, over the whole speed range, always designed with a constant steering ratio between the steering wheel and the road wheels, the ratio can be changed actively and dynamically with the aid of the ZF Active Steering. This possibility enables new driver assistance and vehicle dynamic functions with the aim of increasing driver comfort and safety.

Principle of angle superposition on the Active Steering

\[ \delta_{\text{Pinion}} = \frac{1}{i_e} \delta_{\text{Steering wheel}} + \frac{1}{i_m} \delta_{\text{Motor}} \]

\( i_e = \) ratio between steering wheel and pinion
\( i_m = \) ratio between motor shaft and pinion
System Configuration

Principle diagram of a ZF Active Steering in the steering column with basic steering ZF Servolectric of paraxial design

1 ZF Servolectric
2 Steering column
3 Actuator
4 Steering intermediate shaft
5 Steering pinion
6 Electronic control unit

Servolectric® is a registered trademark of ZF Lenksysteme GmbH
Compact, advantageous package.

At the heart of the ZF Active Steering in the steering column (2) lies the actuator (3), formed by a superposition gear system (wave gear) and an electric motor. The Active Steering unit transmits both the steering angle input by the driver via the steering wheel and the additional motor angle (superposition angle), which is generated by the electric motor, via the steering intermediate shaft (4) to the steering pinion (5) of the power steering gear (1). This means that, via the superposition gear system, a front wheel steering angle can be generated both by the driver and the electric motor, independently of one another.

The electric control unit (6) evaluates the instantaneous driving condition with the aid of sensor information and, depending on the result, controls the superposition angle.

The actuator with superposition gear system can be integrated into the steering column or alternatively into the steering gear.

Integration of the Active Steering actuator into the steering gear is advantageous, as there is no influence on the friction down to the steering valve and the acoustic emission of noise into the engine compartment is less noticeable. Mechanical transmission takes place by a combined worm and planetary gear train.

The steering column solution offers considerable advantages regarding package design. Its compact dimensions permit the use of the Active Steering even on vehicles where there is not sufficient installation space for the steering gear variant. The dynamic requirements and the efficiency of each of the two variants are comparable.
superposition gear system, enclosed in a lightweight metal housing, the Active Steering unit is able to generate, within split seconds, the additional steering angle requested by the vehicle electronics as required by the current situation. The conventional steering feel is not adversely affected by this.

The superposition gear system design is based on a wave gear principle. It is basically composed of three concentrically arranged parts: the elliptical wave generator (2), the flex spline (a flexible cylinder) with external teeth (3), and a circular spline (a solid steel ring) with internal teeth (4).

The hollow shaft (2), which is centrically seated in the electric motor forms, together with the wave generator, a single unit. A flexible ball bearing (5) causes the area of the teeth of the flex spline to be deformed in line with the elliptical external contour of the wave generator. This causes the teeth in the opposite areas of the major axis of the ellipse (11) to be always safely in mesh with the solid circular.

Superior interaction of mechanical components, electrics and electronics.

The actuator is the defining component of the ZF Active Steering in the steering column. Through an additional motor angle, the actuator produces a kinematic superposition to the steering wheel angle. With its main subassemblies electric motor (1) and
spline with internal teeth. In the area of the minor axis of the ellipse (12), however, there is no contact among the two tooth systems. The flex spline can be driven by both the circular spline and the universal shaft (6) that is positively connected with it or by the wave generator.

When the wave generator rotates, the major axis of the ellipse shifts and with it, the tooth engagement area. Because the circular spline has two teeth more (number of teeth = 102) than the flex spline (number of teeth = 100), there results, after half a rotation of the wave generator, a relative movement of one tooth between the parts and, after a full rotation, a relative movement of two teeth. For instance, 51 revolutions of the electric motor are necessary, assuming the steering wheel is static, to move the circular spline and thus the steering pinion by one rotation (ratio $i = 1:51$).

If the driving situation does not require an additional angle, the interconnected wave generator/electric motor unit does not move. In that position, for one rotation of the steering pinion 1.02 steering wheel turns are required (ratio $i = 1:1.02$). In practice, this minimal ratio difference provides the direct mechanical connection when the motor does not provide a motion.

The steering wheel angle input by the driver and the additional angle from the motor are combined at the circular spline and transmitted to the rack via the steering intermediate shaft and the steering pinion. The displacement of the rack results in an effective steering angle at the road wheel that may be larger or smaller than determined by the base mechanical ratio, depending on the direction of rotation of the motor.

A brushless, electrically commutated direct-current motor (BLDC motor) is used. For the control of the motor angle, a motor angle sensor (8) is used to determine the instantaneous motor position. The performance of the control system is very high: it is both very precise and provides the ability to generate a defined motor angle within split seconds.

### Practical example: Driver turns steering wheel through 100° …

<table>
<thead>
<tr>
<th>Steering system (speed)</th>
<th>Driver Steering wheel angle</th>
<th>Actuator Motor angle</th>
<th>Steering gear Pinion angle</th>
<th>Vehicle Wheel angle</th>
<th>Effect Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>... without Active Steering (whole speed range)</td>
<td>100°</td>
<td>not available</td>
<td>100°</td>
<td>6°</td>
<td>Same relationship between steering wheel angle and wheel angle over the whole speed range</td>
</tr>
<tr>
<td>... with Active Steering (at 20 km/h)</td>
<td>100°</td>
<td>+ 25°</td>
<td>125°</td>
<td>7,5°</td>
<td>Larger wheel angle at the same steering wheel angle Increased driving comfort</td>
</tr>
<tr>
<td>... with Active Steering (at 150 km/h)</td>
<td>100°</td>
<td>- 25°</td>
<td>75°</td>
<td>4,5°</td>
<td>Smaller wheel angle at the same steering wheel angle Increased driving safety</td>
</tr>
</tbody>
</table>
Intelligent and highly dynamic.

The electronic control unit developed for the ZF Active Steering in the steering column establishes the connection between the electrical system of the vehicle, the vehicle sensors, as well as the steering sensors and the actuator. All the components required for the control of the ZF Active Steering are installed on a multilayer board. The control unit is designed for operation at ambient temperatures of -40 °C to +70 °C.

The core component of the electronic control unit is a high-capacity microprocessor with the pertinent smart watchdog for monitoring. This processor evaluates the signals from the vehicle and steering system sensors and calculates the control outputs for the actuator. Via the power output stages, which are also integrated into the ECU, the electric motor is then driven, and the actuator is controlled such that the desired position is reached. If a hydraulic power steering is installed, a controllable ECO valve at the steering pump can
additionally be actuated (ECO = Electronically Controlled Orifice).

To meet the high safety requirements for the steering system, the electronic control unit monitors all connected components for correct function. Additionally, all functions which have an influence on the motor angle are calculated redundantly on the microprocessor. If an error is detected, countermeasures are initiated immediately. The functional safety is achieved by applying ISO 26262.

The program memory of the ECU uses flash technology. This allows the programming of the whole software by means of a central plug in the vehicle. The high flexibility ensured by this makes it possible to incorporate updated or extended software levels during service visits, therefore ensuring state-of-the-art technology for the functions of the Active Steering.

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**Modular AFS system concept**

*linked with a vehicle dynamics controller*
With ZF Active Steering, ZF Lenksysteme makes an Active Steering system which is capable of implementing both steering assistance functions and driving stabilizing functions. The various steering assistance functions can individually be parameterized and adapted to the vehicle by the vehicle manufacturers. Defining the functions and responsibility for these can either lie with ZF Lenksysteme or with the vehicle manufacturer concerned, depending on their design.

Beyond being a classic steering aid, the ZF Active Steering can provide a variable steering ratio, which depends on, for example, vehicle speed. Depending on the driving situation, the effective steering angle at the road wheels becomes larger or smaller than the angle defined by the driver at the steering wheel. When driving slowly in road traffic, a direct steering ratio facilitates parking and negotiating sharp turns. The
The car reacts more directly and comfortably and is easier to handle. At high speeds, the electric motor intervenes in a direction opposite to the movement of the steering wheel, thus slightly reducing the wheel turning motion. The steering system becomes more indirect, and the car is more stable and safer. The driver needs no longer fear that he will lose control of the vehicle as a result of an inadvertent sharp steering motion. The ECU decides if, and by what amount, the steering angle has to be altered.

Another comfort feature is the steering lead. Depending on the rate at which the driver turns the steering wheel, an extra angle of lead is generated by the Active Steering. The faster the driver turns the steering wheel, the larger that angle becomes. This can significantly reduce the existing vehicle response time as a result of a steering motion.

Also, steering interventions to improve vehicle stability are possible. In addition to the stabilizing braking interventions of the Electronic Stability Program (ESP), steering interventions by the Active Steering can be carried out for stabilization in safety-critical driving situations. Thus, vehicle dynamic systems will be able to influence the vehicle no longer only by braking interventions, but also by the steering system. Advantage: the intervention in the steering gear is very fast and hardly noticeable to the driver. This linking of Active Steering and ESP demonstrably contributes to increased driving safety.

The combined use of Active Steering with an electric steering gear offers potential for future steering functions. Their networking makes it possible to freely create both the effective steering angle and the steering torque of
a steering motion. These functional degrees of freedom allow the achievement of steer-by-wire functions without having to separate the mechanical connection between the steering wheel and the steered wheels. Due to these possibilities and the great appeal for the final customer, ZF Active Steering will gain widespread acceptance.

Like any product developed by ZF Lenksysteme, Active Steering too, must be in agreement with vehicle manufacturers’ goals and support. At this early stage, there is a vision of a completely integrated chassis management within the automotive industry. An overriding electronic control unit will identify critical driving conditions and activate the corresponding subsystems such as ESP, ZF Active Steering, Rear Axle Steering or Active Roll Control to make the best contribution to safe vehicle handling. These networking possibilities show the potential for manufacturer-specific combinations of suspension control systems.
Our Company is headquartered in Schwäbisch Gmünd, Germany. This is also where development work on the ZF Active Steering is carried out. By concentrating our expertise in mechanical systems, software, electrics, electronics and electric motors in one location, we are able to respond to our customers' needs more quickly.

Positioned as the technology and innovation leader in the steering market, ZF Lenksysteme serves as a reliable and professional partner to vehicle manufacturers around the globe. A rigorous focus on satisfying the needs of vehicle manufacturers and end customers lays the foundation for the company's performance, while ground-breaking technological solutions form the basis for the market success of its products. The successful Active Steering, which is available for many vehicle types, is an impressive example of this.

### Comprehensive Expertise for Active Steering Development

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<th>Actuator</th>
<th>Electronics</th>
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<td>Sensor</td>
<td>Electronic control unit (ECU)</td>
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<td>Gear system</td>
<td>Software</td>
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<tr>
<td>Motor</td>
<td>Functions</td>
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<td>Locking unit</td>
<td>Safety</td>
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<td>Mechanical interfaces</td>
<td>Electrical interfaces</td>
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<td>Acoustics</td>
<td>Vehicle test</td>
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Steering system (electric/hydraulic)  
Steering column

*All AFS development areas are in one location*
ZF Lenksysteme GmbH: the systems partner

ZF Lenksysteme GmbH is one of the largest independent manufacturers of power steering systems for passenger cars and commercial vehicles. Renowned automotive manufacturers from all over the world value us as a creative and efficient systems partner for the development of new and innovative solutions.

As a joint venture of Robert Bosch GmbH and ZF Friedrichshafen AG, ZF Lenksysteme GmbH offers its customers a unique source of expertise when it comes to integrating a wide range of top technologies in modules, system modules or entire chassis systems.

The benefits for the manufacturer are clear to see: even shorter development times and optimized production processes – with quality standards which just get better and better.