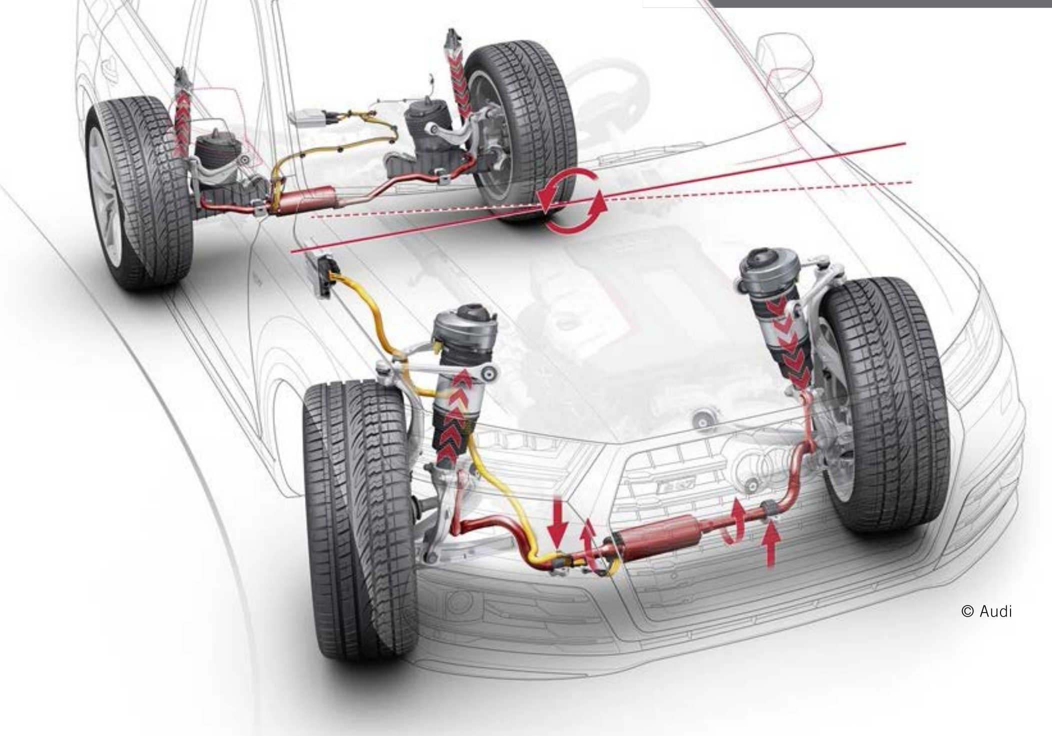
Mechatronic Roll Control for the 48-V Electrical System



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Active chassis systems in SUVs provide a improved driving stability due to the supporting sensor and control technology. Schaeffler developed an mechatronic Active Roll Control (eARC) which is now based on a more powerful 48-V vehicle electrical system and reduces roll copying.

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SUVS AS A HOT TOPIC

For the last few years, there has been an increasing trend in the availability of Sport Utility Vehicles (SUV) to automobile buyers. These passenger cars provide the purchaser with a combination of qualities such as power, size and off-road driving as well as comfort. The trend is so clear that even the premium automobile manufacturers have ventured into this market segment. And with success, as the sales figures show [1]. The aim of Schaeffler's mechatronic Active Roll Control (eARC), as will be shown in this article, is to improve driving comfort whilst simultaneously increasing vehicle dynamics and safety. Even – or exact – in the rapidly growing SUV segment.

SYSTEM BENEFITS

Unlike passive stabilisers, in active systems, the two stabiliser halves are connected by a mechatronic actuator which provides the torsion between the halves. Suitable sensor technology and signal processing supports the system in achieving a significantly improved perception of the vehicle's stability by reducing the roll angle. At the same time, there is a reduction in the vehicle's so-called roll copying when excitation occurs on only one side and it is also possible to vary the distribution of the support between the front and rear axles.

The objective when using eARC system depends on the vehicle to which it is fitted. Similarly, it also depends on the car manufacturer installing the system. However, the focus is always on the characteristics mentioned before. Due to the design of the system and the ease with which it can be parameterised, it is therefore possible for a car manufacturer to make the system its "own" – even on different platforms. The effect can be either greater comfort or greater dynamics, without compromising safety.

In this respect, car manufacturers have to ask themselves one important question concerning the integration of the eARC system into the existing vehicle architecture, and that is, which vehicle electrical system to use: 12 V or 48 V voltage. There are advantages to both voltages. The benefits of the 48-V variant lie in power density and wire cross-sections. Schaeffler offers a solution for both voltages: The 48-V system will be discussed in greater detail in this article.

The topology shown in **FIGURE 1** shows an eARC system connected to a Volkswagen platform architecture. This clearly shows that the eARC control units are connected to both vehicle electrical systems (12 and 48 V). The algorithms required for the roll control are distributed between various control units. The higher-level vehicle control unit determines the specific requirements for the driving situation: This is based on the vehicle information and is matched to the required characteristic. This also takes the coordination between the front and rear axles into consideration in order to optimise the vehicle performance. The eARC system translates these requirements into an appropriate support at both axles.

ASSEMBLY AND FUNCTIONALITY OF THE SYSTEM

The mechatronic actuator, consisting of a motor/gearbox unit including halves of the torsion bar and the wire harness, combined with the signal processing, provides highly dynamic actuation. The functionality on a single axle includes controlling the two main functions of disturbance decoupling and anti-roll support.

On uneven road surfaces or in the event of impact excitations, both torsion bar halves are decoupled from each other by the motor/gearbox unit. This ensures there is considerably less movement in the body and reduces roll copying. This produces a noticeable increase in driving comfort. The increase in comfort due to the reduction in roll accelerations is shown in the left-hand section of **FIGURE 2** as a comparison to a passive stabiliser.

In order to counteract the roll movement in the bodywork during sporting, dynamic driving, the two torsion bar halves are twisted against each other by the motor/gearbox unit when turning and when negotiating curves. As described in the right-hand section of **FIGURE 2**, vehicle roll is reduced or eliminated completely. This results in a firm, sports handling similar to a reduced understeering.

A particular benefit resulting from the support is the reduction in the tyre camber angle and therefore a greater surface area of tyre on the road. This produces a greater maximum lateral acceleration when cornering which results in a shift of the driving dynamics limits to higher values. Furthermore, it is also possible to match the vehicle's inherent steering behaviour to a driving situation as the support can be distributed between the front and rear axles on a variable basis [2]. The eARC system thus resolves the conflict between setting up the chassis for either comfort or performance which is not an option when using conventional stabilisers.

The benefits of the mechatronic system compared to a hydraulic active roll control are maintenance-free operation and a straightforward integration, both during development and later in production. The eARC also contributes to reducing emissions as it operates on the principle of power on demand. In spite of this, the full performance capability of the system is available for use even at low speeds.

The eARC system comprises an actuator and a control unit on each axle of the vehicle. These are connected by means of a fixed actuator wire harness. **FIGURE 3** shows the installation as it would appear on the front axle of an Audi SQ7. The actuator consists of the motor/gearbox unit including halves of the torsion bar and the wire harness. The two halves of the torsion bar act as the mechanical connection between the actuator and the vehicle. They are connected to the chassis by connecting rods on one side and to the sub-frame of the vehicle by plat-

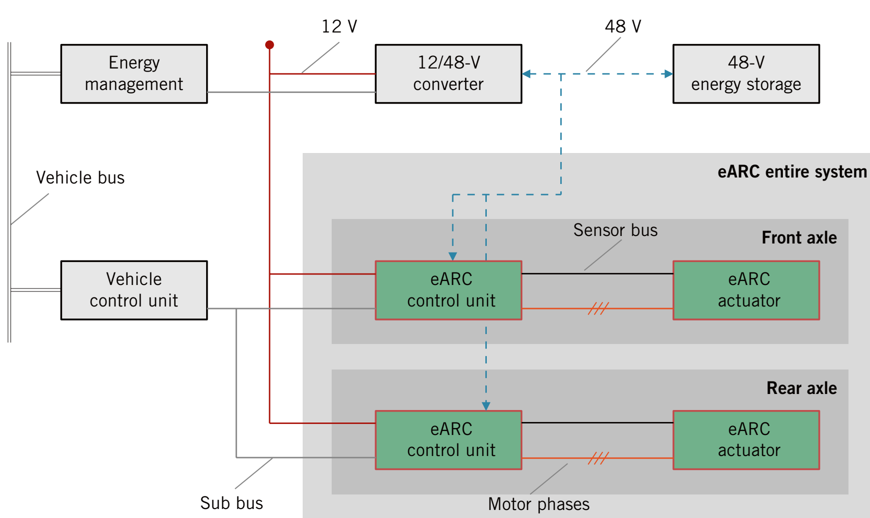

FIGURE 1 Control unit topology and connecting of the eARC entire system to the vehicle architecture (© Schaeffler)

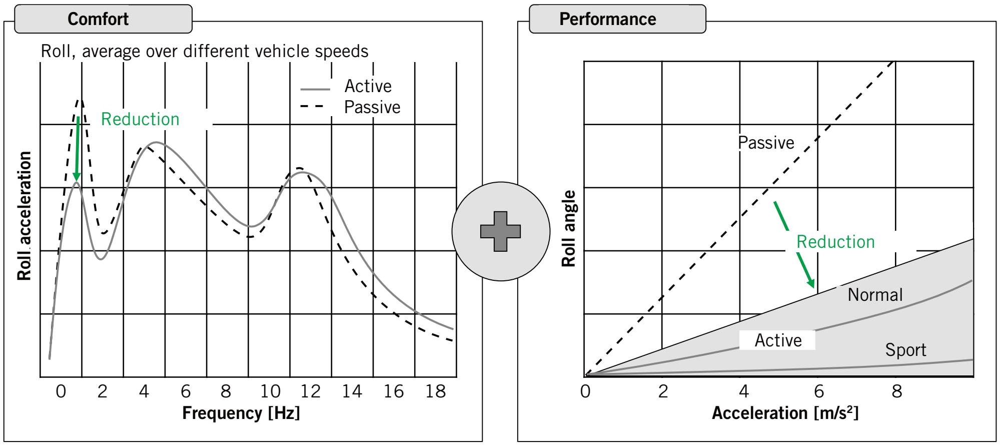

FIGURE 2 Qualitative presentation of reductions in roll accelerations and roll angles due to the eARC system for increase in comfort (left) and performance (right) [2] (© Porsche)

form-specific stabiliser bearings on the other side.

Right from the early stages of its development, the eARC system has been conceived for use in a range of vehicles types as well as in different series. So, for example, customers' space requirements can be accommodated as the actuators and control units are separate items. The eARC is currently being used on two Volkswagen platforms (MSB and MLBevo) with seven different types of actuator. This requires a high degree of flexibility during development and production in order to be able to accommodate the variations. At the same time, it is vital to ensure that as many components as possible are used multiple times for reasons of cost. It is obvious that each platform has different requirements in terms of the package and integration into the axle and bodywork. In any event, the possible solution space is therefore restricted to where all vehicle types overlap. There are also additional requirements specific to each user such as load requirements, system dynamics and acoustics.

In order to be able to achieve the functions described above on a vehicle level, the eARC system must have the following characteristics [2]:
- maximum rotation angle: ±30°
- maximum adjustment speed: 4500 Nm/s
- maximum support torque: 850 to 1200 Nm.

For this reason, the actuator in **FIGURE 4** is optimised to the highest possible transmission efficiency and high dynamics for the electric motor. It always has the same basic design.

The electric drive is a brushless DC electric motor (BLDC) which has been developed for a 48-V application. The sensor board for assessing position is incorporated in this unit. The three-stage planetary gearbox is optimised in terms of its friction and is supported by internal gear teeth on the housing. In order to minimise running noise, the first stage has helical gear teeth. The planets in the third stage are preloaded against each other in order to damp impulses on the tooth faces.

The different eARC systems are distinguished by variations in the halves of the torsion bar and the wire harness: These are matched to the load, cable routing and space requirements of the OEM. The control unit, including software, can be used on all actuator types and axles. Final adjustments are completed in the vehicle during parameterisation.

By using a 48-V vehicle electrical system, the eARC is able to call off high peak electrical loads of over 1.5 kW per axle and to feed energy back. It is very difficult to achieve similar performance data using the conventional 12-V equivalent. Separating the actuator from the control unit as described above also improves the heat management. Furthermore, the higher voltage allows smaller

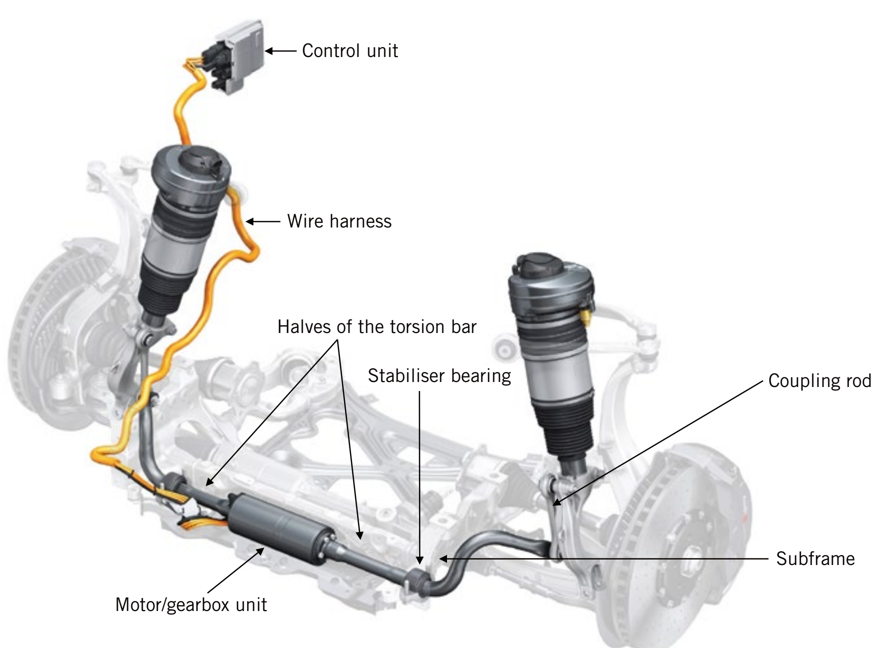

FIGURE 3 eARC system components and their installation in a front axle configuration for an Audi AQ7 (© Audi, Schaeffler)

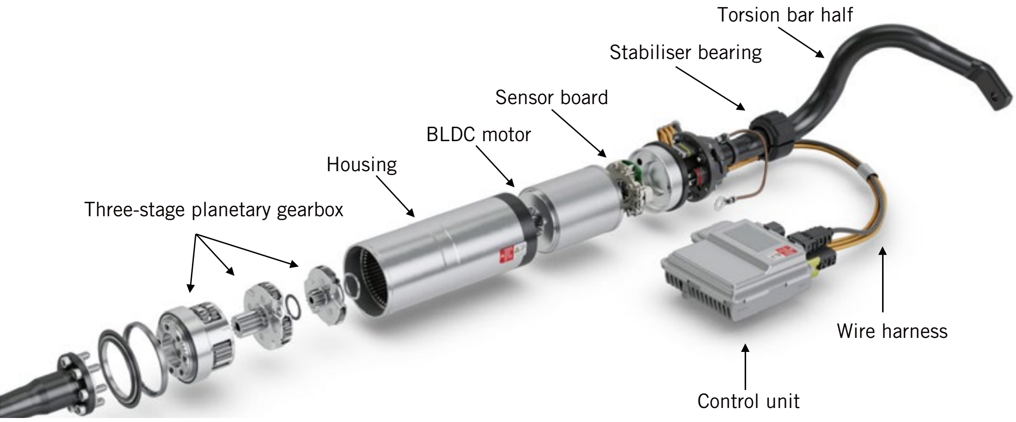

FIGURE 4 eARC system actuator assembly (© Schaeffler)

wire cross-sections to be used which improves the cable routing and the overall system package.

The control unit commutates the rotor in the three-phase BLDC motor using the sensor board in the actuator. A bus system provides the communication between the sensor and the control unit. A specifically designed protocol is used to guarantee the signal integrity and the required data rate. Optimum control of the actuator by the controller is guaranteed by individual parameters. These are determined for each actuator during production in order to maintain the required tolerances. The parameters are transmitted to the control unit together with the type code and axle information.

CONTROLLING THE SYSTEM

The actuator control, which was developed in-house by Schaeffler, is a central component of the eARC mechatronic roll control, **FIGURE 5**. This unit provides precise engagement of the active stabiliser with the chassis, at exactly the right time, and thus forms the basis of targeted control of driving comfort and driving dynamics. The conflict between these two development goals can thus be resolved by adjusting the parameterisa-

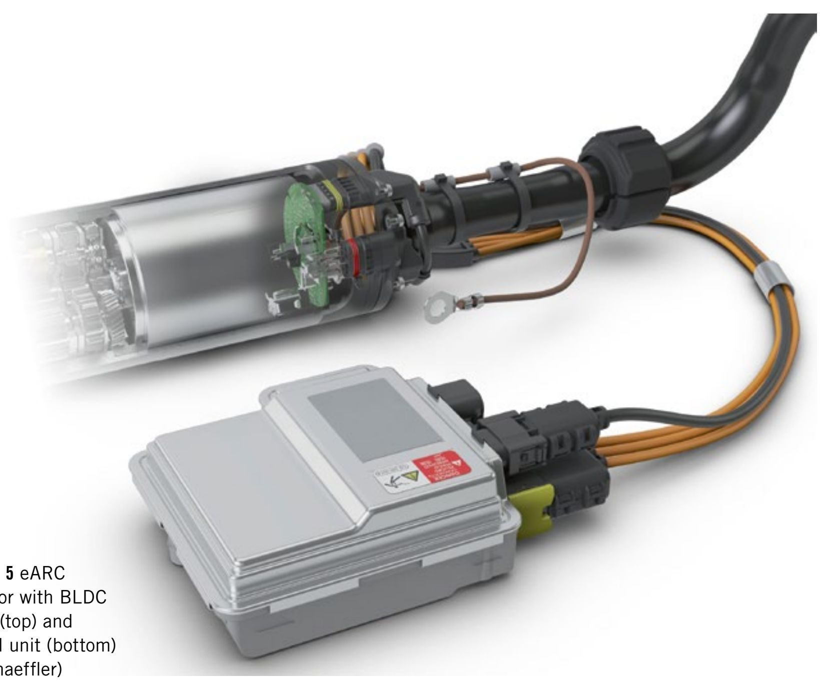

FIGURE 5 eARC actuator with BLDC motor (top) and control unit (bottom) (© Schaeffler)

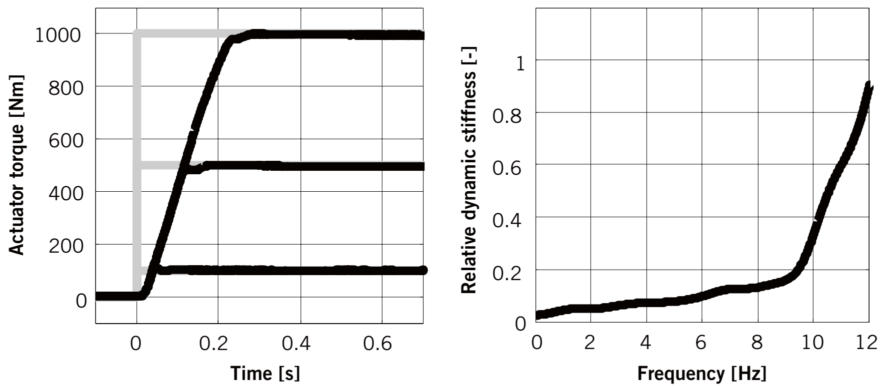

FIGURE 6 Step response of the actuator torque (left) and relative dynamic rigidity of the actuator (right) (© Schaeffler)

tion during runtime to suit specific situations.

The control is based on a modular principle and has a cascade structure which provides high flexibility as well as a high degree of reusability in equal measure. The use of modern, model-based design methods guarantees the robustness required for volume production as well as an automatic adjustment of the control to suit specific actuator parameters.

The basic functions of anti-roll support during lateral acceleration and disruption decoupling when driving on poor road surfaces pose the greatest challenge from a control technology perspective due to their high dynamic requirements. The actuator control developed by Schaeffler allows the potential which has been generated in the active roll control system to be fully exploited due to the system's consistent design (for example by deciding on the 48-V vehicle electrical system) and to make a significant contribution to increasing both the driving comfort and the agility of the vehicle. This also applies in the event of significant disruption such as driving over a curb while cornering and just as shifting the voltage level in the vehicle electrical system.

The data from measurements shown in **FIGURE 6** provide an index for this for both the step responses of the actuator torque (left) and the achievable relative dynamic stiffness of an actuator (right). The very low step times can be seen as a direct response behaviour or very good anti-roll support in the vehicle while the dynamic rigidity, which has a wide frequency range below the rigidity of a comparable passive system, accounts for the high levels of driving comfort.

SUMMARY

Schaeffler has collaborated closely with its customers to overcome the challenges in the development of the mechatronic active roll control. This system provides OEMs with a dynamic driving system which offers an extraordinary drive through curves and increased comfort on uneven roads – as well as a safe and highly dynamic drive.

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