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PRESS INFORMATION

More than 40 years of quattro

Condensed information

Four rings, four-wheel drive: Four times ten years of quattro

- **Technology and success story: about 11.2 million all-wheel drive Audi vehicles produced since 1980**
- **There is a custom-designed quattro solution available for each technology concept.**
- **New quattro technology with electric torque vectoring in the Audi e-tron S* and e-tron S Sportback***

“quattro” means “Audi,” and “Audi” often means “quattro”: The principle of four-wheel drive is a cornerstone of the brand and has been for 40 years. Since the original quattro made its debut at the Geneva Motor Show in 1980, Audi has produced about 11.2 million cars with quattro drive systems while always advancing all-wheel drive technology. The latest state of development is the electric quattro with electric torque vectoring.

Over 40 years of quattro: the track record and the model range

The quattro has built up an impressive track record over more than 40 years. Through 2020, Audi had produced 11,199,144 cars with all-wheel drive. Some 45.31 percent of all Audi models produced in 2020 were equipped with a quattro drive system – it is a cornerstone of the brand with the four rings. It is available in every model series except the compact A1. All large and particularly powerful vehicle versions, as well as all S and RS models, transfer their horsepower to the road through all four wheels.

quattro 2.0: electric all-wheel drive and electric torque vectoring

With the e-tron* and the e-tron Sportback*, Audi entered not only the age of sustainable electric mobility in 2019 but also the era of electric all-wheel drive. Electric motors drive the front and rear axles in both SUV models. The suspension and drive control units work closely together to regulate the ideal distribution of drive torque between them – continuously, fully variably and within fractions of a second.

For reasons of efficiency, the electric SUVs use only the rear electric motor in most situations. If the driver requests more output than it can provide, the front unit will instantly be activated.
This also happens predictively before slip occurs in icy conditions or during fast cornering, or if the car understeers or oversteers. The result is extremely precise handling that can be adjusted to a large extent via the suspension control systems, from supremely stable to sporty.

At the beginning of 2020, Audi upped the ante with the first expansion stage of the electric all-wheel drive: electric torque vectoring in the Audi e-tron S* and the Audi e-tron S Sportback*, i.e. shifting the forces between the rear wheels, which are each powered by separate motors.

The equipment, data and prices specified in this document refer to the model range offered in Germany. Subject to change without notice; errors and omissions excepted.

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It takes just milliseconds to engage extremely high torque, allowing the car to be driven into curves as energetically as a sports car. Audi is the first manufacturer in the premium segment to mass-produce the technology using three electric motors.

An all-star line-up: the variants of the mechanical quattro drive

The Audi quattro technology is versatile and tailored precisely to suit the specific vehicle concept. One thing that all models do share is the way the system works in concert with wheel- selective torque control – a function of Electronic Stabilization Control (ESC) that assists handling at the limits of adhesion by gently applying the brakes at appropriate moments.

There are two technologies available for models with longitudinal front-mounted engines, depending on transmission. The quattro permanent all-wheel drive, which cooperates with the tiptronic torque-converter automatic transmission, centers on a purely mechanical self-locking center differential. In regular driving, it distributes 40 percent of the torque to the front axle and 60 percent to the rear axle, creating a slight rear bias for a sporty driving style. If necessary, it will transfer up to 70 percent to the front axle or up to 85 percent to the rear.

However, quattro with ultra technology – which has been optimized for efficiency and can be found in Audi models with S tronic or with manual transmissions – uses a dual-clutch arrangement. When the system changes to efficient front-wheel drive, the front clutch – a multi-plate clutch at the transmission output – disconnects the propshaft. An integrated decoupling clutch also opens in the rear differential. This shuts down the primary cause of drag losses in the rear section of the drivetrain. The all-wheel drive system's intelligent control works predictively, always looking ahead via a comprehensive array of sensors and continuous analysis of the data on driving dynamics, the road condition, and driver behavior. The quattro all-wheel drive system is thus always ready when needed. Drivers will not notice any differences in terms of traction and handling compared with permanent systems.

The compact Audi models with transverse engines use their own quattro drivetrain. At its core is a hydraulic multi-plate clutch that sits on the rear axle for better weight distribution. This is managed so dynamically that it can transfer some of the torque from the front axle to the rear as soon as the car starts to turn in to a corner. There is also a multi-plate clutch in the R8, a mid-engined high-performance sports car. In this case, it is mounted on the front axle. When necessary, it transfers the torque from the rear wheels to the front wheels steplessly.

Over 40 years of quattro: the milestones

When the Audi quattro first appeared at the Geneva Motor Show in 1980, it introduced a means of transmitting power that was entirely new in the passenger car sector – an all-wheel drive system that was lightweight, compact, efficient and low-tension. This made the quattro concept particularly suited to fast, sporty cars and high-volume production right from the outset.

The 147 kW (200 PS) original quattro remained part of the product range as a standard model until 1991 and underwent several technical revisions. In 1984, Audi added the exclusive "short" Sport quattro with an output of 225 kW (306 PS).

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With the introduction of the Audi 80 quattro in 1986, the center differential that could be locked only manually until then was replaced with the first self-locking center differential. It provided purely mechanical distribution of the drive torque between the front and rear axles at a 50:50 ratio. Under load, it transferred up to 75 percent to the axle with better traction as needed.

The brand continued to refine its quattro technology in subsequent years. The Audi A6 2.5 TDI, the first diesel with permanent all-wheel drive, was launched in 1995. In 1999, quattro technology in the form of an electro-hydraulic multi-plate clutch was introduced in the A3 and TT model series and thus in the compact segment with transverse engine configurations. The next big step came in 2005 with the center differential with asymmetric, dynamic 40:60 power distribution between the front and rear axles. When the first Audi R8 was introduced in 2007, a viscous coupling appeared on the front axle, followed a year later by the rear axle sport differential. In 2016, the quattro with ultra technology optimized for efficiency was added to the portfolio, and Audi launched the electric all-wheel drive on the market in the e-tron* in 2019.

Over 40 years of quattro: supremacy in motorsports

Audi first entered the World Rally Championship in 1981, and the quattro drive dominated the event just one season later. The Audi team won the manufacturers' championship in 1982, and Finnish driver Hannu Mikkola secured the drivers' trophy in 1983. Audi took both titles in 1984, with Stig Blomqvist of Sweden becoming world champion. That year, Audi fielded its Sport quattro with a short wheelbase for the first time, followed in 1985 by the Sport quattro S1 producing 350 kW (476 PS). In 1987, Walter Röhrl drove a specially modified S1 to victory at the Pikes Peak hill climb in the USA – the perfect finishing touch to the exhilarating years of rallying.

Audi subsequently shifted to racing touring cars. In 1988, the manufacturer won both the drivers' and manufacturers' championships in the US Trans-Am at its first attempt with the Audi 200, before competing with considerable success in the IMSA GTO series the following year. In 1990/91, Audi entered its mighty V8 quattro in the Deutsche Tourenwagenmeisterschaft (DTM), winning two drivers' championships. The A4 quattro Supertouring entered seven national championships in 1996 – and won them all. Two years later, the European ruling bodies banned all-wheel drive almost completely from touring car races.

An Audi all-wheel drive race car – the Audi R18 e-tron quattro with a hybrid drive – once again took to the track in 2012. A V6-TDI powered the rear wheels, while a flywheel accumulator supplied recuperated energy to two electric motors on the front axle. The car used a temporary quattro drive system during acceleration. It boasted a formidable track record, with three overall victories at the 24 Hours of Le Mans and two drivers' and manufacturers' titles in the World Endurance Championship (WEC).

Over 40 years of quattro: Vorsprung durch Technik

quattro is an icon. The name represents safe driving and sportiness, technical expertise and peak performance in the competitive environment – in short, Vorsprung durch Technik. The success of quattro models on the road and in racing has cemented this status, as has a series of legendary TV commercials and advertising campaigns.

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In 1986, professional rally driver Harald Demuth drove an Audi 100 CS quattro up the Kaipola ski jump in Finland. In 2005, Audi repeated this event with an S6 on the same ski jump, which was restored specially. Circuit and rallycross champion Mattias Ekström (Sweden) performed a similar feat in 2019: He tackled the steepest uphill section of the infamous Streif ski course at Kitzbühel in a technology demonstrator and predecessor to the Audi e-tron S* with three electric motors, negotiating gradients of as much as 85%.

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Facts and figures

40 years of Audi quattro

The track record

- About 11.2 million Audi cars with quattro drive systems produced since 1980
- Track record through 2020: 750,733 Audi quattro produced worldwide
- quattro technology installed as standard in every S and RS model; currently 33 such models on the market in Germany

The mechanical quattro technologies

A wide-ranging array of technologies:

- quattro permanent all-wheel drive and quattro with ultra technology for models with longitudinal front-mounted engines, plus sport differential for many top models
- quattro with different versions of the multi-plate clutch for models with transverse engines and the R8 sports car

Electric all-wheel drive and electric torque vectoring

- Electric all-wheel drive in the Audi e-tron* and e-tron Sportback* provided by two separately controlled electric motors
- Audi e-tron S* and e-tron S Sportback* have thee electric motors, each with two electric motors on the rear axle for electric torque vectoring

The technical milestones

1980 to 1999

- Original quattro in 1980 and Sport quattro in 1984 with manually locking center differential
- 1986: First self-locking center differential
- 1999: TT and A3 with electronically controlled hydraulic multi-plate clutch

2000 to 2020

- 2005: First self-locking center differential with asymmetric, dynamic power distribution (40:60)
- 2007: Audi R8 with viscous multi-plate clutch
- 2008: Sport differential for the rear axle
- 2016: quattro with ultra technology
- 2019/2020: Audi e-tron* with electric all-wheel drive and Audi e-tron S with electric torque vectoring
- 2021 Audi RS 3* with torque splitter for fully variable torque

quattro in motorsports

1980s

- Four titles in the World Rally Championship from 1982 to 1984; three victories in the Pikes Peak hill climb from 1985 to 1987; then major success in the Trans-Am and IMSA GTO series in the USA

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1990s

- Drivers' championships in the DTM in 1990 and 1991; seven titles in the Super Touring category in a single season in 1996

2010s

- Three Le Mans victories and four WEC titles for the Audi R18 e-tron quattro

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Over 40 years of quattro – over 40 years of *Vorsprung durch Technik*

40 years of quattro: the highly successful technology from Audi

A technological success story from Audi: the quattro drive system is already over 40 years old. Since the original quattro first made its debut in 1980, the principle of four-wheel drive has become one of the cornerstones of the brand. To date Audi has sold almost 11.2 million cars with quattro drive. The most recent chapter of the success story is electric: The Audi e-tron* uses electric all-wheel drive, and the e-tron S* models already feature its first expansion stage: electric torque vectoring, i.e. the need-based shifting of torque between the rear wheels.

The track record

"quattro" means "Audi," and "Audi" often means "quattro." Now, 40 years after the original quattro first appeared, the brand with the four rings has notched up some impressive figures. Through 2020, Audi had produced 11,199,144 cars with all-wheel drive. Some 45.31 percent had all-wheel drive in 2020.

The quattro drive system has been one of the biggest cornerstones of the Audi brand for 40 years. It is represented in every model series except the compact A1. All larger models – the A8, the Q7, the Q8, the e-tron*, and the e-tron Sportback*, the R8 and all S and RS models transfer their horsepower to the road through four wheels as standard. Audi currently has 16 quattro models in its portfolio on the German market.

The mechanical quattro systems

Throughout its model range, Audi offers a very wide variety of car concepts – and quattro technology is equally multifaceted. One thing that all versions share is a supplementary solution: Wheel-selective torque control is a software function of Electronic Stabilization Control (ESC). During dynamic cornering, it applies the brakes very gently to the unloaded wheels on the inside of the curve before they have the chance to slip. Due to the difference in propulsion forces, the car turns slightly into the corner. This input makes the handling even more neutral, dynamic and stable.

Two systems: quattro drive for longitudinal engines

The Audi models with longitudinal front-mounted engines and tiptronic automatic transmissions employ the classic quattro drive system with a self-locking center differential, which operates by purely mechanical means and therefore without any delay whatsoever. It is configured as a planetary gear. This involves an internal gear encompassing a sun gear, with cylindrical planet gears, joined to the rotating housing, turning between them.

In regular driving operation, 60% of the drive torque flows to the rear axle via the internal gear, which has a larger diameter, and its associated output shaft.

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The remaining 40% goes to the front axle via the smaller sun gear. This asymmetric, dynamic torque distribution results in sporty, rear-biased basic handling. If the wheels on one axis lose traction, the geometry of the gearwheels and helical gearing in the differential produce axial forces. These forces act on friction discs to produce a locking effect that diverts the bulk of the drive torque to the wheels with the better traction. Up to 70% can be directed to the front wheels and up to 85% to the rear.

The quattro with ultra technology optimized for efficiency is designed for Audi models featuring a longitudinal front-mounted engine working with a manual transmission or the S tronic dual-clutch transmission. During moderate driving, quattro with ultra technology enjoys all the advantages of front-wheel drive. All-wheel drive remains continuously available however, and is there immediately when needed.

The control system for the quattro powertrain is comprehensively networked. It acquires and evaluates data – in ten millisecond cycles – such as the steering angle, transverse and longitudinal acceleration and engine torque. As a result, all-wheel drive is generally activated predictively, i.e. in anticipation of the need for it. When cornering at speed, the control unit detects roughly half a second in advance when the wheel on the inside of the curve will reach the traction limit and quickly sends drive torque to the rear wheels. There are no differences in terms of traction and handling compared with conventional permanent quattro drive systems.

The concept with two clutches in the drivetrain gives quattro with ultra technology a significant efficiency advantage of on average roughly 0.3 liters of fuel per 100 kilometers *(62.1 mi)* over the competition. When the system changes to front-wheel drive, the front clutch – a multi-plate clutch at the transmission output – disconnects the propshaft. A decoupling clutch also opens in the rear differential. It shuts down the rotating components that cause the most drag losses here, such as the large crown wheel running in the oil bath.

Mechanical torque vectoring at the rear axle: sport differential

The sport differential is available for the particularly powerful and sporty Audi models with tiptronic. It further improves handling, traction, and stability by distributing drive torque ideally between the rear left and right wheels in all operating states. During turning or acceleration, mechanical torque vectoring literally presses the car into the curve without producing any understeer.

In addition to the functions covered by a conventional differential, the sport differential has a transmission stage and hydraulic multi-plate clutch fed by an oil pump. During fast cornering, the clutch engages for the wheel on the outside of the curve, which has better grip due to the dynamic wheel load distribution. The clutch variably imposes a higher speed on the transmission stage for the relevant wheel. The extra torque required is taken from the opposite wheel via the differential, which means that almost all the torque goes to the wheel on the outside of the curve. Up to 1,200 Nm *(885.1 lb-ft)* of drive torque can be transferred to one wheel in this way.

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Hydraulic multi-plate clutch: the quattro drive for transverse engines and the Audi R8

The compact models with transverse engine configurations use a quattro drivetrain centered on an electronically controlled hydraulic multi-plate clutch. It is mounted at the end of the propshaft before the rear differential to optimize weight distribution. Inside it is a package of metal friction rings mounted in alternating order one behind the other. Half of these plates are meshed with the clutch drum, which rotates with the propshaft. The other half is connected with the rear axle differential via a short shaft.

The all-wheel drive control constantly calculates the best torque distribution between the front and rear axles based on numerous data. When the requirements change, the electric axial-piston pump in the clutch builds up as much as 40 bar of hydraulic pressure within just a few milliseconds. It presses the friction plates together, which enables variable transmission of the drive torque from the front axle to the rear. The stronger the pressure, the more torque is directed to the rear axle – up to 100 percent when the clutch is fully closed.

On the especially sporty models with transverse engine layouts, clutch management is designed to focus on dynamics, with more frequent and pronounced rearward torque distribution. The clutch can already transmit part of the torque to the rear when the driver turns the steering wheel with a sporty driving style. This effect assists greatly with the handling. During load changes, the distribution of torque allows precise turning into the bend, which further increases driving dynamics.

The Audi S3* and the revised Q2 use a multi-plate clutch of the latest generation whose control is integrated in the modular dynamic handling control. This new system collects data from all components that are relevant for transverse dynamics and manages the quick and precise interplay between them. When the car is driven with a more restrained style, the clutch can be disengaged entirely to boost efficiency. The new multi-plate clutch is around one kilogram *(2.2 lb)* lighter than its predecessor part while offering increased efficiency thanks to various details such as bearings and oil supply.

In second-generation versions of the R8 high-performance sports car (since 2015), Audi has fitted the electrohydraulic multi-plate clutch in a special drive layout. Behind the V10 mid-mounted engine is a compact seven-speed S tronic along with a locking differential to drive the rear wheels. One of its output shafts is linked to the propshaft that runs to the front-axle drive. It holds the water-cooled multi-plate clutch, which distributes the necessary torque to the front wheels in any driving situation. There is no fixed basic distribution; in extreme cases, up to 100% can be transmitted to the front or rear axle here, too.

quattro 2.0: electric all-wheel drive and electric torque vectoring

With the Audi e-tron* and the e-tron Sportback*, the brand with the four rings is making strides into the sustainable future of transportation – and the future of the quattro drive system. The two electric motors on the front and rear axles enable electric all-wheel drive that ensures the best possible traction and sporty handling.

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The Audi e-tron S* uses electric all-wheel drive, which integrates and reinterprets the strengths of the sport differential.

Audi e-tron* and Audi e-tron Sportback*: Electric all-wheel drive

Electric all-wheel drive regulates the ideal distribution of torque to both axles permanently and fully variably, combining the efficiency of a single-axle drive with the handling and traction of an all-wheel drive. When driven at a calm pace, the Audi e-tron* and e-tron Sportback* use only the rear electric motor for propulsion.

If the driver demands more power than it can supply, the control units will activate the motor on the front axle. This happens predictively in many situations, even before slip occurs in icy conditions or during fast cornering, or if the car understeers or oversteers. It takes just roughly 30 milliseconds from the system detecting the situation to the drive torque for the electric motors kicking in. In combination with wheel-selective torque control, electric all-wheel drive offers excellent traction, outstanding stability, and plenty of fun whatever the weather. To a great extent, the driver can adjust the character of the handling via the suspension control systems, from supremely stable to sporty.

In the Audi e-tron S* and e-tron S Sportback*, Audi is presenting the latest generation of electric all-wheel drive. Each of the two exceptionally dynamic electric SUVs comes with three electric motors on board, allowing drivers to experience the benefits of the classic sport differential on the rear axle. Each of the two rear electric motors actuates one rear wheel directly via its transmission. As with the axles, there is no mechanical link. Electric torque vectoring, that is the distribution of torque between the rear wheels, is performed in a matter of milliseconds, and it is possible to engage extremely high torque.

If the car turns into a curve quickly, the electric motor will direct extra torque to the rear wheel on the outside of the curve, while the brakes will be applied to the inside rear wheel accordingly. The difference can amount to as much as 220 Nm *(162.3 lb-ft)*, which translates to around 2,100 Nm *(1,548.9 lb-ft)* at the wheels as a result of the gear ratios. These values are higher as compared to a mechanical system. In addition, the latency, that is the time offset, is four times shorter.

All control units involved in electric all-wheel drive and the electric sport differential work closely together, which is what makes the high speed and precision of the control operations possible in the first place. Electronic Stabilization Control (ESC), the drive control unit (DCU), the electronic chassis platform (ECP), and the power electronics control units all have roles to play.

Audi RS 3*: quattro drive system with electrically controlled multi-plate clutch

For the first time in an Audi, the torque splitter is being used in the new Audi RS 3*: it enables active, fully variable torque distribution between the rear wheels. Unlike the rear axle differential and the existing multi-plate clutch package on the rear axle, the torque splitter uses an electronically controlled multi-plate clutch on each drive shaft.

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For sportier driving, it increases the torque on the rear wheel on the outside of the curve, which significantly reduces the tendency toward understeering. When driving on closed roads, the torque splitter enables controlled drifts.

One step ahead of the competition: the technical milestones

quattro technology can trace its roots back to the winter of 1976/77, when a team of Audi engineers conducted a series of test drives in the deep snow of Sweden. An Iltis traveled along for comparison purposes, and the all-terrain military vehicle with its high ground clearance outperformed the much more powerful front-wheel-drive prototypes. During this trip, it dawned on the engineers that Audi could realistically use the all-wheel drive system even on high-performance passenger cars – but it would have to be a completely new type that was lightweight, compact, and efficient, and could manage without a heavy transfer case or second propshaft.

The stroke of genius that made it all possible was the hollow shaft – a drilled-out, 263 millimeter *(10.4 in)* secondary shaft in the transmission that directed power in two directions. From its rear end, it drove the housing of the center differential, which was configured as a manually locking bevel-gear differential. In normal situations, it sent 50% of the power along the propshaft to the rear axle, which was equipped with a second locking differential. The other half of the torque was transferred to the front axle's differential along an output shaft rotating inside the secondary shaft. The quattro drive system was born. The center differential has evolved continuously since then.

Since 1980: quattro technology for longitudinal engines

The new technology made its first appearance at the Geneva Motor Show in 1980, fitted to the Audi quattro, an angular coupé with a five-cylinder turbocharged engine delivering 147 kW (200 PS). Originally planned for only low-volume production, the original quattro ended up remaining part of the model line-up until 1991, having undergone numerous refinements along the way. In 1984, it was joined by the Audi Sport quattro with a short wheelbase. Producing 225 kW (306 PS), it was an exclusive high-performance sports car at the time.

With the new Audi 80 released in 1986, the brand introduced the second generation of its quattro technology, featuring the Torsen differential (Torsen: torque sensing), which was designed as a worm gear transmission. The new differential was accompanied by an enormous technological advance and provided a technical basis that has undergone extensive further development and is still used today. When a vehicle axle lost traction, friction would be created in the helical gears of the differential, allowing up to 75% of the torque to be diverted to the other axle. These higher locking figures enabled a clearly defined torque distribution in every driving situation.

The next big step in the evolution of the models with longitudinal front-mounted engines came in 2005 with the Audi RS 4. The new planetary gearing distributed the forces in a rear-biased 40:60 ratio in normal conditions. This third generation of the center differential has undergone further stages of development since then. The current generation can distribute 85% of the drive torque to the rear axle and up to 70% to the front axle as needed.

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1999 onward: new developments across all technical platforms

Audi has continued to expand its range of quattro models over the course of 40 years. The decision was made back in the early 1980s to offer the quattro drive system across the board. The new models helped to pave the brand's way into the premium segment. The first TDI with permanent all-wheel drive appeared in 1995; four years later, the technology moved into the compact class. The A3 and the new TT featured the electronically controlled hydraulic multi- plate clutch.

The first generation of the Audi R8 high-performance sports car launched in 2007. Its quattro drive system was a very special development, with the transmission in the rear integrating a power take-off supplying an unregulated viscous coupling on the front axle via a propshaft. It could divert 15% to 30% of torque to the front wheels when conditions called for it. In the second-generation version of the R8 (2015), the viscous clutch was replaced with a controlled multi-plate clutch.

The sport differential for the powerful A and Q models came in 2008, making its debut in the Audi S4*. Finally, the quattro system with ultra technology optimized for efficiency joined the technology line-up when it arrived in the Audi A4 in 2016. As the most recent major innovation in the mechanical quattro world to date, it solved the conflict of objectives between dynamic handling and efficiency. With the electric all-wheel drive and electric torque vectoring, Audi opened up a completely new chapter in technology history in the e-tron family in 2019.

quattro in motorsports

Audi entered the world of rallying as a works team in 1978, initially running front-wheel drive cars. Barely a year had passed since the original quattro was first unveiled in Geneva than the brand began to achieve enormous success in the World Rally Championship. Hannu Mikkola of Finland won the first six special trials in the snow at the 1981 Monte Carlo Rally. He had a lead of almost six minutes when victory slipped through his fingers due to a minor accident. He recorded his first victory at the next round in Sweden.

1982–1987: supremacy on gravel

The following year, the quattro dominated the championship. Audi set a new benchmark with seven victories and easily won the manufacturers' championship. One year later, Mikkola took home the drivers' title. The 1984 season also started off with a bang – the newly recruited two-time world champion Walter Röhrl won the Monte Carlo Rally ahead of his teammates Stig Blomqvist (Sweden) and Mikkola. At the end of the season, Audi claimed both the manufacturers' title and the drivers' title with Blomqvist.

To make better use of the loose regulations of the Group B class of rallying, Audi developed the Sport quattro for the 1984 season. This had a shorter wheelbase that promised nimbler handling. It was followed in 1985 by the Sport quattro S1, which developed 350 kW (476 PS) and was instantly elevated to legendary status due in part to its striking rear spoiler. In the middle ratio, the 1,090-kilogram *(2,403.0 lb)* S1 shot from 0 to 100 km/h *(62.1 mph)* in 3.1 seconds.

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In the last event of the season, the British RAC Rally, Walter Röhrl used a dual-clutch transmission that was actuated pneumatically – a precursor to today's S tronic.

When the exhilarating Group B years came to an end in 1986, Audi pulled out of the World Rally Championship – but not without one last bombshell. In July 1987, Röhrl triumphed at the Pikes Peak hill climb, driving an extensively modified Sport quattro S1 adorned with some enormous wings. Michèle Mouton (France) and Bobby Unser (USA) had already won the classic race in the US State of Colorado in the two previous years. Walter Röhrl tackled the 19.99-kilometer *(12.4 mi)* course, very little of which was paved at the time, in a record time of 10 minutes and 47.85 seconds, hitting a top speed of 196 km/h *(121.8 mph)*. As he noted, "It was the very pinnacle of what can be done with a rally car."

1988–1992: success in touring car racing

The brand competed in the Trans-Am series in the USA with the Audi 200 in 1988, winning the manufacturers' and drivers' titles at the first attempt, the latter courtesy of US driver Hurley Haywood. Haywood and Hans-Joachim Stuck scored seven wins out of 15 races in the IMSA GTO series in 1989, when the regulations were a little more relaxed. The five-cylinder turbo in their Audi 90 quattro hit top form at around 530 kW (720 PS).

Audi switched to the Deutsche Tourenwagenmeisterschaft (DTM) touring car championship in 1990. Stuck won the drivers' title with the big and powerful V8 quattro that first year, followed by Frank Biela in 1991. By the time Audi withdrew from the series in 1992, it had won 18 out of 36 races. In 1996, the Audi A4 quattro Supertouring, with its two-liter, four-cylinder engine, entered seven national championships on three continents – and won them all. Because of its supremacy, the European rules largely banished all-wheel drive from touring car competition two years later. The quattro's record up to that point read as follows: four titles in the World Rally Championship, three victories at Pikes Peak, a championship win in the Trans-Am, two DTM titles, eleven national touring car championships and a World Touring Car Cup.

2012–2014: three overall victories at Le Mans

It wasn't until 2012 that an Audi all-wheel drive race car – the Audi R18 e-tron quattro with hybrid drive – once again took to the track for a circuit race. A V6 TDI drove the rear wheels, while a flywheel accumulator supplied recuperated energy to two electric motors on the front axle. When the situation called for maximum traction during acceleration, the racing car was capable of throwing its temporary quattro drive system into the mix for a few crucial seconds. With three consecutive overall victories at the 24 Hours of Le Mans and two drivers' and manufacturers' titles in the World Endurance Championship (WEC), Audi provided a convincing demonstration of the potential of the concept.

The enduring appeal of quattro

quattro is an icon. The name represents safe driving and sportiness, technical expertise and competitive superiority. The success of quattro models on the road and in racing has laid the foundation for this, while a series of legendary TV commercials has served only to underline it.

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One unforgettable moment is the clip from 1986 filmed at the Kaipola ski jump in Finland, featuring the red Audi 100 CS quattro with professional rally driver Harald Demuth at the wheel scaling the 37.5-degree incline under its own power. In 2005, Audi repeated this feat on the same ski jump, which was restored specially for the event, with an S6. Circuit and rallycross champion Mattias Ekström (Sweden) performed a similar feat in 2019. He tackled the steepest section of the *Streif* ski course at Kitzbühel in an Audi e-tron quattro* with three electric motors, negotiating gradients of as much as 85%.

Audi has fueled the appeal of quattro again and again over 40 years with a succession of spectacular concept cars. The quattro Spyder, presented at the 1991 International Motor Show (IAA) in Frankfurt am Main, Germany, was the brand's first thoroughbred sports car of the post-war era and its first aluminum-bodied car. Just a few weeks later, Audi presented the Avus quattro at the Tokyo Motor Show. It was designed to feature a W12 engine producing 374 kW (509 PS) mounted longitudinally ahead of the rear axle, the manual transmission in the quattro drivetrain positioned between the front wheels.

The Audi TT quattro Coupé and Roadster concepts presented in fall 1995 indicated the way to series production. Three more concept cars marked the expansion of the model range in 2003. At the Detroit Motor Show in January, Audi presented its Pikes Peak quattro, the predecessor to the Q7. This was followed at the Geneva Motor Show by the Nuvolari quattro two-door coupé, which paved the way for the A5. Then, in September, the Audi Le Mans quattro was the star of the IAA in Frankfurt – and also the spitting image of what would later become the R8.

The Audi R8 e-tron concept, one of the stars of the IAA in 2009, was a sports car with electric- only drives at all four wheels. In 2010, the Audi quattro concept – a re-interpretation of the original quattro – appeared at the Paris Motor Show. From 2015 on, numerous concept cars heralded the future arrival of standard e-tron models with electric all-wheel drive: the Audi e-tron quattro concept (IAA 2015), the Audi e-tron Sportback concept (Shanghai 2017), the Audi e-tron GT concept (Los Angeles 2018), and the Audi Q4 e-tron concept (Geneva 2019).

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From real life

From the Arctic Circle to the Nürburgring: a conversation with quattro developers

Audi has been testing its quattro systems under extreme conditions for many years now – with considerable effort, a deft touch and a meticulous approach. We brought together experts from various development areas to talk about the process. Dieter Weidemann (drive) and William Wijts (suspension) explain how they test the purely mechanical center differential on snow and ice. Roland Waschkau from Audi Sport GmbH is the sport differential specialist, while Stefan Lehner (suspension) has a very different responsibility – he develops and tests software for the electronically controlled quattro systems. And his colleague Marc Baur (suspension) specializes in electric torque vectoring.

Mr. Wijts, Mr. Weidemann, your testing work takes you all around Europe – including winter testing on snow and ice. Why is that particularly important for you?

Weidemann: We do tuning work on ice and snow because this allows the subtle differences between the different quattro variants to be clearly distinguished. Routes with a low coefficient of friction are the most important challenge for us. Although this involves operating at the limits of driving dynamics, one of our main aims is to ensure that the car is controllable for everyday drivers, i.e. people who might unintentionally find themselves at the limits on slippery roads in ordinary driving. They are the reason why we develop and test the quattro drive, particularly on snow, in order to guarantee safe and comfortable handling.

What happens on these test drives?

Wijts: Our name for the site is “Kalt 1.” It’s located near the Arctic Circle. To tune the center differential, we typically travel to Sweden with four or six cars, supported by one or two mechanics. We tend to go in February, when the terrain is covered in deep snow and the weather conditions are at their most stable. The private test site has a wide range of different routes, some of them with outward banking corners and other intricacies. There are multiple handling courses on the lake and on land that have been specifically designed to allow us to test different cornering profiles and cornering speeds. The site even has a serpentine road for traction tuning.

Weidemann: We work best at temperatures below 5 °C *(41 °F)*. This makes the conditions broadly constant and allows us to reliably compare the various configurations. At the same time, a reference vehicle is always needed in order to properly judge how the conditions are changing. The best conditions of all are -25 °C *(-13 °F)* with really hard snow that offers good grip, but it never stays like that for the whole day. The second test run is already different from the first, the snow gets flattened, and the ice gets polished, and so the conditions gradually deteriorate. But we are familiar with this effect and know how to take it into account.

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How risky is your work?

Wijts: The worst that can happen on the lake is you fly off the edge and have to be dug out of the snow. When it comes to land handling at the private test site, we know the routes so well by now that we can analyze the intricacies of tuning without difficulty. At the same time, we take the limits of physics very seriously. Within these limits, we drive as fast as necessary for our work – at 30 km/h *(18.6 mph)* in some sections, at 160 km/h *(99.4 mph)* in others.

Weidemann: When we are tuning center differentials, we deactivate as many of the suspension control systems as possible, including ESC, so that we can evaluate the quattro drive in isolation. Our aim is for the basic driving characteristics to be harmonious even without the control systems, so the car does exactly what the driver wants. Incidentally, this strategy once surprised a high-ranking colleague from technical development who had moved to Audi from a direct competitor and was accompanying us in Sweden for the first time. After a test run in an A6 with quattro drive, he told us enthusiastically about how smoothly and harmoniously the control systems worked. But they had all been deactivated.

You are well practiced when it comes to winter testing. How long have you been involved?

Wijts: My first winter test was in 1998. Back then, the requirements in terms of the Torsen differential were far lower than they are today – the priority was that it had to be robust and capable of generating as little tension as possible in tight corners and when maneuvering. Then Dieter came along. He was already very interested in how the cars drive. The suspension and drive development teams have been pushing each other forward ever since.

Weidemann: Our department took on responsibility for the quattro drive and restructured the development process. Together with our colleagues from the suspension team, we gradually developed a shared philosophy. We selected very different basic distributions and locking values for the front and rear axle and examined their functionality, initially on the test bench. We then took the most promising differentials with us to Sweden. The most intensive period of development was in the late 2000s, when we were investigating fundamental concepts for the self-locking center differential using entirely different technologies. It wasn't unusual for us to set off with 30 different components or more.

How long did winter testing take back then?

Wijts: Ten years ago, it took around two weeks – with no weekends off. And every day followed the same pattern: Driving, letting the mechanics make modifications, driving again… After that, we developed a concept that we still use today. We define the different models that we intend to use in the test drives in advance – an S4* and an SQ7*, for example. This is important because the differentials are used in very different classes of vehicle, after all.

Weidemann: We then take two identical vehicles of each model type with us, both containing the standard self-locking center differential.

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The car that performs slightly better becomes our first reference car. We install one of the prototype differentials in the other car and see whether it improves the driving characteristics. If it does, that car becomes the new reference, and the next development variant is installed in the first car. This allows us to optimize the driving characteristics iteratively until we have worked through all of the variants.

Do you always agree in your assessment?

Wijts: Dieter and I discuss the performance of the car in detail, like how it behaves during load changes or whether there is too much or too little understeer. In the end, we always agree. Just like an old married couple [laughs].

What are the properties of the ideal self-locking center differential?

Wijts: Every customer should be able to drive an Audi quickly and safely on snow and ice. This means we place great importance on ensuring that the car responds the same way in every situation where possible, that it steers spontaneously and takes corners neutrally. And when the rear does break away during a burst of acceleration, for example, it is important that the movement is not too dramatic so the car remains easy to handle. It also needs to have very good traction, of course.

Weidemann: It goes without saying that Audi has made immense progress with the mechanical quattro system since 1980. Today's basic distribution of 40 percent to the front axle and 60 percent to the rear axle, combined with the right locking values, means there is an excellent overlap in terms of strong grip and good handling. However, its main strength is and remains the traction it provides on surfaces with a low coefficient of friction.

Waschkau: For customers looking for dynamic driving on dry roads, we offer our sport differential, the quattro sport, for the rear axle. This makes the car agile by actively shifting the drive torque between the rear wheels as required. Race tracks and high coefficients of friction also play an important role in tuning, particularly for the RS models. Unlike the traditional center differential, the sport differential is an electronically controlled system. It consists of two clutches and a superimposed transmission, while the software is specially adjusted and fine- tuned for each vehicle.

Another controlled system is the quattro with ultra technology. What inspired its development?

Weidemann: A survey around ten years ago found that many Audi customers who did not drive a quattro believed the additional consumption to be far higher than it actually is, and had not yet experienced the strengths of the all-wheel drive. The quattro is for more than just icy and snowy conditions – it is already beneficial when turning or moving off on dry asphalt. In other words, there are many situations where customers can briefly enjoy the benefits of the quattro drive, but there are also many driving scenarios where no difference between the quattro and front- wheel drive are visible.

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Consequently, we decided to develop an entirely new system with a switchable rear axle that combines the high efficiency of a front-wheel drive with all of the benefits of permanent all-wheel drive.

Wijts: Our objective was to make it so there was no noticeable difference compared with the permanent quattro. We created 15 computational models describing the differences in areas like the feel of the steering. In other words, we were able to identify exactly when the steering on a front-wheel drive car feels lighter than on a quattro as the load increases, or the point at which it begins to tramline. The rear-axle drive is temporarily engaged in all of these situations. This always happens preemptively, so the all-wheel drive is already active by the time it is needed.

How difficult was it to tune and test the quattro with ultra technology?

Weidemann: We had the advantage that the legal safety requirements for the test were low – even if the system had failed completely, the car would have continued with the normal front- wheel drive. This meant we could begin road testing extremely early in development, which was very good news in terms of maturity. As we often do, we drove a 120-kilometer *(74.6 mi)* loop around Ingolstadt on public roads. This allowed us to continuously double-check the progress of the software versions, which is very useful and important. It meant we were able to work through all the different driving situations, from southern Italy to the Arctic Circle, like a customer would in real life and adjust our operating strategy to ensure that the driving characteristics were the same as for the permanent quattro.

Speaking of the operating strategy and software: Mr. Baur and Mr. Lehner, this is where you come in.
Lehner: Our department looks after the mechatronic and fully electric quattro systems. We develop software functions such as clutch actuation under changing conditions and demands. We are involved in every controlled system. In the mechanical world, this means the quattro drive for the R8, for vehicles with longitudinally mounted engines and the quattro ultra, and the quattro for cars based on the MQB platform. They use a hydraulic multi-plate clutch where efficiency of control is also extremely important. Under normal, smooth driving conditions, the drive is largely provided via the axle that is driven directly. The drive torque is smoothly distributed to all four wheels as necessary.

Baur: And then we have the e-tron models with the electric all-wheel drive that no longer contains any physical all-wheel components – nothing mechanical or hydraulic at all. Each axle has one or even two motors which combine to produce the electric quattro.

How does your testing process work? You must have a lot of digital screws and levers at your disposal...

Lehner: Yes, there are thousands of potential parameters for the software, depending on how finely they are tuned and combined. We gradually narrow them down to a reasonable number, ending up with around 100 to 200 property parameters.

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We use them to tune the traction and the handling individually for each model derivative, for example. Testing takes place the traditional way during a test drive: One of the team sits in the passenger seat with a laptop and repeatedly loads different software versions into the system. We take the same corners, lap after lap, until we find the ideal end result.

Do you do more testing on the road or on the test track?

Lehner: When a project begins, there are various reasons why we are not allowed to take cars on the road yet, so we have no choice but to use the test site. What that does mean is conditions can be reliably replicated and we can take things to the limit when driving. Sometimes we only drive for an hour, then spend five hours at a desk analyzing the measurements. Then, in the second phase of development when things are heading toward series production, we spend a lot of time in the car simulating various customer situations. That involves winter roads in Sweden, Alpine roads with cracked and crumbling surfaces, and also the famous Nordschleife loop at the Nürburgring – because it packs a lot of specific challenges into a small space, like changing surfaces and banked corners. In direct contrast, we also do test drives in parking garages, because concrete has a very low coefficient of friction and the turns are very tight.

The more complex the all-wheel system, the more extensive its development and testing. Is that right, Mr. Baur?

Baur: Yes, increased complexity means more functions and parameters. In the e-tron*, the clutch between the front and rear axle is fully emulated by the software, resulting in tens of thousands of lines of code and countless parameters. The big challenge is tuning the systems involved – particularly in the S* model with its three electric motors. In this particular case, we worked in close cooperation with our colleagues who developed the drive control unit and the control units for the power electronics and the brake control system. We have to develop a large number of functions while always taking into account the various repercussions they can have on other systems. We have the very same aim as our colleagues: to ensure that the car demonstrates predictable and reproducible behavior in every situation.

How does your testing work?

Baur: When we go to the test site, we often have a team of 20 or 30 people working in close cooperation, from various departments of drive and suspension development. We all sit at the same table and, when it comes to testing, in the same car – figuratively speaking, at least.

Weidemann: What I find endlessly intriguing about the quattro is its diversity. I am responsible for all of the components that distribute torque between the axles in the models with longitudinally mounted front engines – and that is just one part of the big picture. However the quattro drive is realized from a technical perspective, it is always synonymous with a high degree of safety, strong traction, and dynamic handling. These are our great strengths. Audi has gained experience in these areas over many generations of quattro models.

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Our objective is to work together to leverage all of the available potential so that we can give our customers the greatest possible benefit and ensure that they are fascinated by Audi.

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Product and Technology Communications
Eva Stania
Tel.: +49 152 57767044
E-mail: eva.stania@audi.de
www.audi-mediacenter.com/de

The Audi Group, with its brands Audi, Ducati and Lamborghini, is one of the most successful manufacturers of automobiles and motorcycles in the premium segment. It is present in more than 100 markets worldwide and produces at 19 locations in 12 countries. 100 percent subsidiaries of AUDI AG include Audi Sport GmbH (Neckarsulm, Germany), Automobili Lamborghini S.p.A. (Sant'Agata Bolognese, Italy), and Ducati Motor Holding S.p.A. (Bologna/Italy).

In 2020, the Audi Group delivered to customers about 1.693 million automobiles of the Audi brand, 7,430 sports cars of the Lamborghini brand and 48,042 motorcycles of the Ducati brand. In the 2020 fiscal year, AUDI AG achieved total revenue of €50.0 billion and an operating profit before special items of €2.7 billion. At present, 87,000 people work for the company all over the world, 60,000 of them in Germany. With new models, innovative mobility offerings and other attractive services, Audi is becoming a provider of sustainable, individual premium mobility.

Fuel consumption of the models named above
Information on fuel/electricity consumption and CO_2 emissions in ranges depending on the tires and alloy wheel rims used and on the equipment and accessories of the car.

Audi e-tron
Combined electric power consumption in kWh/100 km (62.1 mi): 26.1–21.7 (WLTP); 24.3–21.4 (NEDC); combined CO_2 emissions in g/km (g/mi): 0 (0)

Audi e-tron Sportback
Combined electric power consumption in kWh/100 km (62.1 mi): 25.9–21.0 (WLTP); 24.0–20.9 (NEDC); combined CO_2 emissions in g/km (g/mi): 0 (0)

Audi e-tron S
Combined electric power consumption in kWh/100 km (62.1 mi): 28.4–26.2 (WLTP); 26.3–25.1 (NEDC); combined CO_2 emissions in g/km (g/mi): 0 (0)

Audi e-tron S Sportback
Combined electric power consumption in kWh/100 km (62.1 mi): 28.1–25.8 (WLTP); 26.0–24.6 (NEDC); combined CO_2 emissions in g/km (g/mi): 0 (0)

Audi S3
Combined fuel consumption in l/100 km: 7.4–7.2 (31.8–32.7 US mpg); combined CO_2 emissions in g/km: 170–165 (273.6–265.5 g/mi)

Audi RS 3
Combined fuel consumption in l/100 km: 8.8–8.2 (26.7–28.7 US mpg); combined CO_2 emissions in g/km: 201–188 (323.5–302.6 g/mi)

Audi S4
Combined fuel consumption in l/100 km: 6.5–6.3 (36.2–37.3 US mpg); combined CO_2 emissions in g/km: 170–167 (273.6–268.8 g/mi)

Audi RS 4 Avant
Combined fuel consumption in l/100 km: 8.8 (26.7 US mpg); combined CO_2 emissions in g/km: 201 (323.5 g/mi)

Audi SQ7
Combined fuel consumption in l/100 km: 12.1–12.0 (19.4–19.6 US mpg); combined CO_2 emissions in g/km: 278–276 (447.4–444.2 g/mi)

The indicated consumption and emissions values were determined according to the legally specified measuring methods. Since September 1, 2017, type approval for certain new vehicles has been performed in accordance with the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), a more realistic test procedure for measuring fuel consumption and CO_2 emissions. Since September 1, 2018, the WLTP has gradually replaced the New European Driving Cycle (NEDC). Due to the realistic test conditions, the fuel consumption and CO_2 emission values measured are in many cases higher than the values measured according to the NEDC. Vehicle taxation could change accordingly as of September 1, 2018. Additional information about the differences between WLTP and NEDC is available at www.audi.de/wltp.

At the moment, it is still mandatory to communicate the NEDC values. In the case of new vehicles for which type approval was performed using WLTP, the NEDC values are derived from the WLTP values. WLTP values can be provided voluntarily until their use becomes mandatory. If NEDC values are indicated as a range, they do not refer to one, specific vehicle and are not an integral element of the offer. They are provided only for the purpose of comparison between the various vehicle types. Additional equipment and accessories (attachment parts, tire size, etc.) can change relevant vehicle parameters, such as weight, rolling resistance and aerodynamics and, like weather and traffic conditions as well as individual driving style, influence a vehicle's electrical consumption, CO_2 emissions and performance figures.

Further information on official fuel consumption figures and the official specific CO_2 emissions of new

passenger cars can be found in the “Guide on the fuel economy, CO_2 emissions and power consumption of all new passenger car models,” which is available free of charge at all sales dealerships and from DAT Deutsche Automobil Treuhand GmbH, Hellmuth-Hirth-Str. 1, 73760 Ostfildern-Scharnhausen, Germany (www.dat.de).