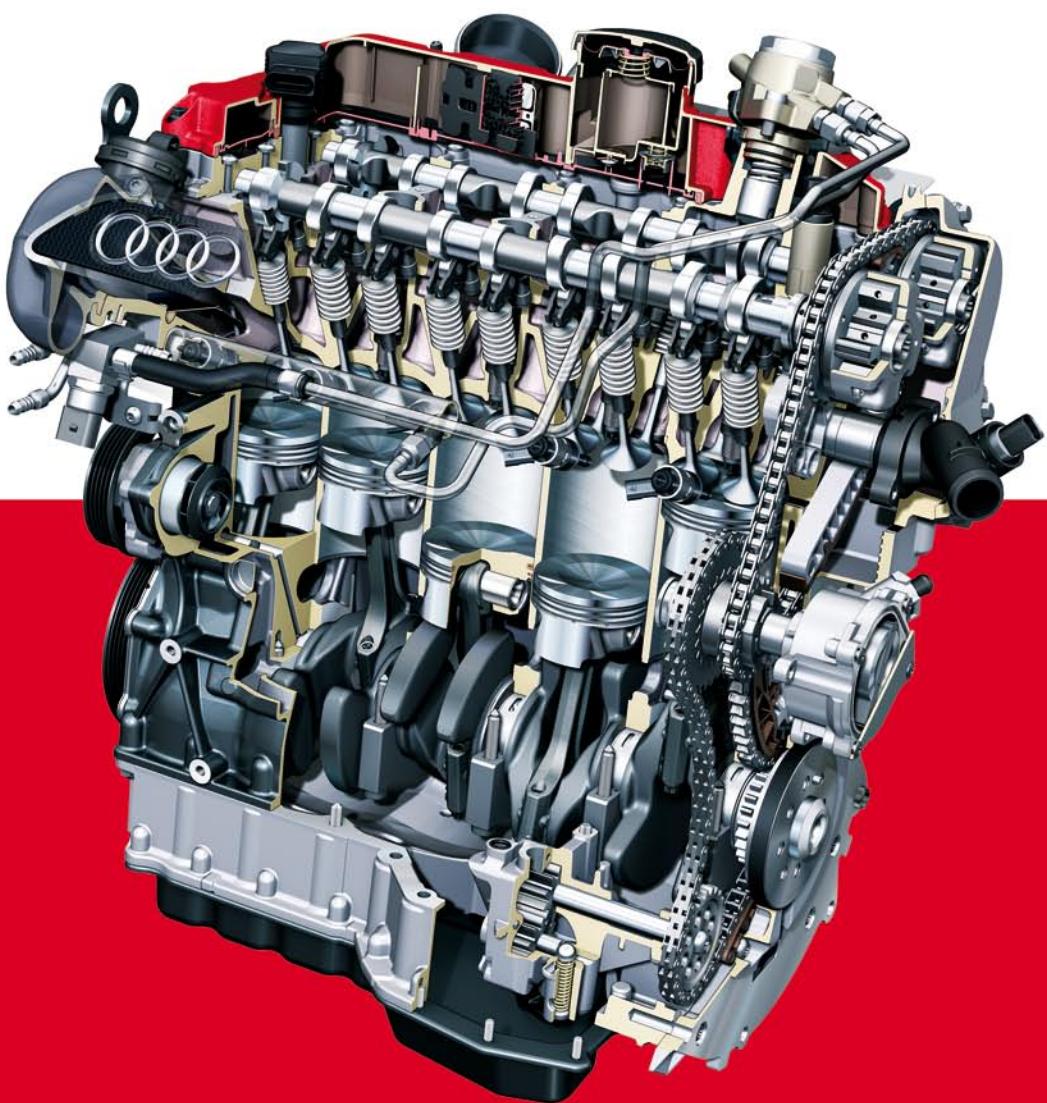


# THE NEW FIVE-CYLINDER 2.5 L TFSI ENGINE FOR THE AUDI TT RS



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Audi has a long tradition of five-cylinder turbocharged engines. The combination of direct fuel injection with turbocharging is a logical advance. A 2.5-litre engine capacity delivers a power output of 250 kW at between 5400 and 6500 rpm and 450 Nm of torque at just 1600 rpm. This engine specification in the Audi TT RS, in conjunction with an optimally adapted six-speed manual gearbox, provides outstanding acceleration and elasticity of sports car proportions allied with reasonable fuel economy.

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## REVIEW

After a break of almost 20 years, Audi once again offers a new five-cylinder in-line engine, which is installed in the Audi TT RS. Audi has been a groundbreaker both in terms of engine development and in the world of motorsport with its five-cylinder design. Throughout its history, from the original quattro to the legendary Audi Sport quattro S1 and the IMSA-GTO models, a whole series of victorious race cars have featured five-cylinder turbo engines.

- : to deliver 250 kW power output in the smallest sportiest Audi model, the TT RS
- : to provide a compact engine/gearbox assembly, owing to the transverse engine configuration in the TT
- : to utilise as many synergies as possible from the base 125 kW MPI induction engine and the Audi engine component kit
- : to deliver driving enjoyment by developing optimum torque in the lower revs range and high power in the upper range.

## DESIGN AND DEVELOPMENT GOALS

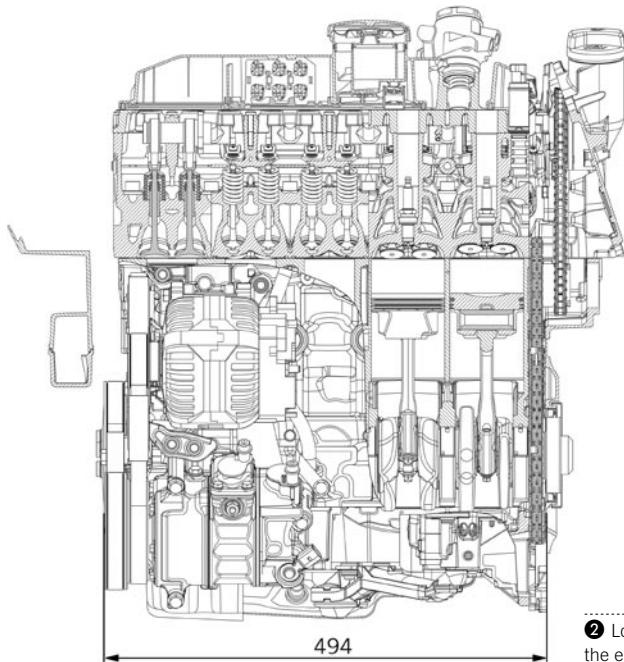
The development goals of the 2.5-litre TFSI engine are as follows:

## DIMENSIONS AND CHARACTERISTICS

① sets out the main dimensions and other characteristic data of the engine. A com-

	UNIT	R5 2.5 L TFSI 250 KW	2.0 4VI TFSI 195 KW	R5 2.5 L MPI 125 KW
<b>CAPACITY</b>	cm <sup>3</sup>	2480	1984	2480
<b>STROKE</b>	mm	92.8	92.8	92.8
<b>BORE</b>	mm	82.5	82.5	82.5
<b>STROKE/BORE RATIO</b>	–	1.12	1.12	1.12
<b>CYLINDER GAP</b>	mm	88	88	88
<b>BLOCK HEIGHT</b>	mm	220	220	220
<b>CONROD LENGTH</b>	mm	144	144	144
<b>CRANKSHAFT BEARINGS</b>	–	6	5	6
<b>MAIN BEARING DIAMETER</b>	mm	58	54	58
<b>CONROD BEARING DIAMETER</b>	mm	47.8	47.8	47.8
<b>VALVE DIAMETER</b>	–			
– INTAKE	mm	33.85	33.85	32.35
– EXHAUST	mm	28	28	28
<b>VALVE STROKE</b>	–			
– INTAKE	mm	10.7	10.7	10.7
– EXHAUST	mm	10	10	10
<b>VALVE TIMING 1 MM STROKE</b>	–			
INTAKE OPENING RETARDED	CA after TDC	28	28	28
INTAKE CLOSING RETARDED	CA after BDC	38	38	38
EXHAUST OPENING	CA before BDC	83	38	28
EXHAUST CLOSING	CA before TDC	23	8	8
<b>INTAKE CAMSHAFT ADJUSTMENT RANGE</b>	CA	42	42	42
<b>EXHAUST CAMSHAFT ADJUSTMENT RANGE</b>	CA	42	–	–
<b>COMPRESSION RATIO</b>	–	10	9.8	9.3
<b>POWER OUTPUT</b>	kW at rpm	250/ 5400 – 6700	195/6000	125/5800
<b>TORQUE</b>	Nm at rpm	450/ 1600 – 5300	350/ 2500 – 5000	230/ 3500 – 4500
<b>FUEL GRADE</b>	RON	98/95	98/95	98/95
<b>INITIAL OIL FILL</b>	l	7	5.3	6.6
<b>WEIGHT ACC. TO DIN 70020 A</b>	kg	183	153	164
<b>EMISSIONS STANDARD</b>	–	EU5	EU4	EU4/ULEV

① Dimensions and characteristics of the engine



② Longitudinal section through the engine [mm]

parison is provided between the R4 2.0 TFSI in the Audi TTS and the R5 2.5 MPI base engine from the VW Jetta [1]. ② shows a longitudinal section through the engine.

#### DESCRIPTION OF THE ENGINE

Transverse-mounted engines with more than four cylinders must be of short design so as to fit the engine/gearbox assembly in the front end of the vehicle between the side members. Audi in-line engines featuring their traditional cylinder gap of 88 mm are ideally designed for the purpose. The length of the engine can be further restricted if the second control drive and belt track can be installed at an offset. The R5 2.5 MPI engine, which has been highly successful on the NAR market since 2004, has those characteristics. When a transverse-mounted engine is turbocharged, the turbocharger, charge air system, charge air cooler etc. must also be installed longitudinally. ② shows the length of the engine as 494 mm. The Audi R5 TFSI is the most compact and powerful engine currently on the market, ③.

The attainment of a short engine length is dictated by the design and dimensioning of the power plant and the engine block. By reducing the width of the connecting rod and the main bearings, the two outer main bearings can be shifted inwards into the engine. This enables space to be saved

by installing the timing chain on the gearbox side and the sealing flange and vibration damper on the front of the engine underneath the water jacket.

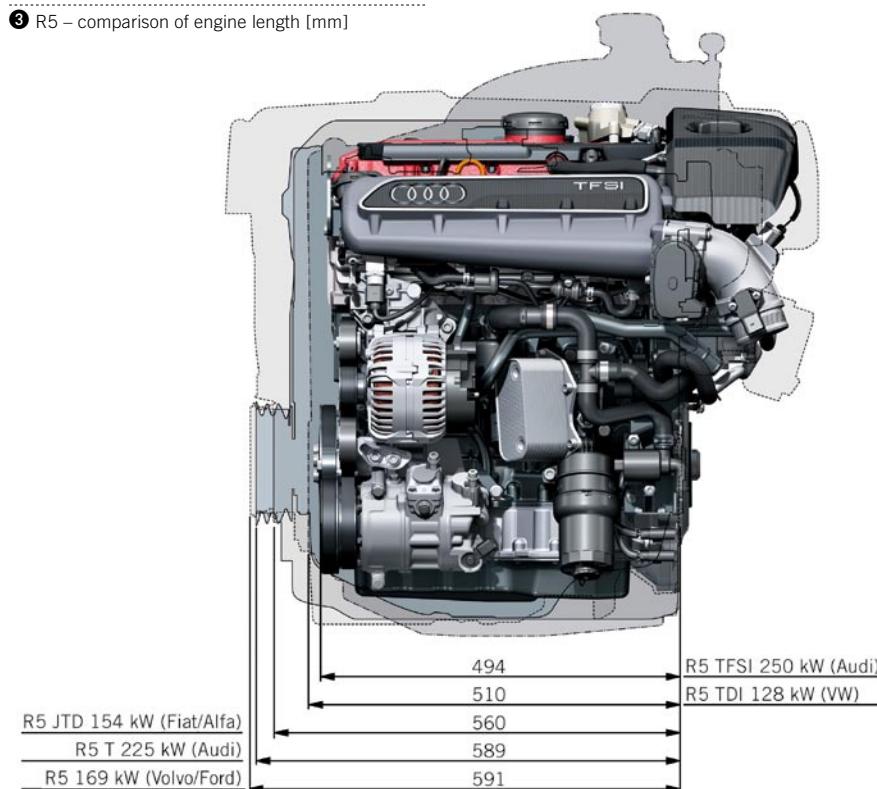
Strength demands means that there are physical limits to the amount by which

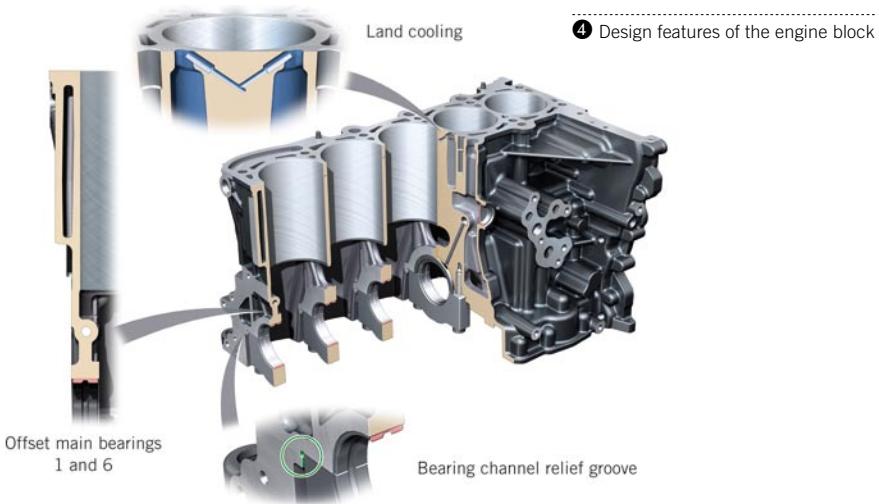
the bearings in a turbo engine can be narrowed, or otherwise a higher-strength material needs to be used. In view of this, a vermicular-graphite cast iron with 450 N/mm<sup>2</sup> tensile strength, which Audi has been using since as far back as 1999 in production of its V6 and V8 TDI engines, was selected as the material for the engine block. For high-revving (up to 6800 rpm) turbocharged direct-injection petrol engines this marked a groundbreaking new development [2]. ④ shows the key design features of the engine block.

The crankshaft is executed as a six-bearing steel shaft, inductively hardened at all crank pins and rolled on the transition radii. The material used is C 38 MOD By. The main and conrod bearing diameters are specified as 58 and 47.8 mm respectively. On the front end of the crankshaft is a visco-damper providing the necessary torsional vibration damping and reducing the torsional load on the crankshaft. At the same time, the high efficiency and the primary-side belt drive design help to reach lifetime of the ancillary drive belts.

The R5 TFSI features a cast aluminium piston with a heat-resistant piston alloy and a mini ring carrier as well as an asymmetric shaped pin bore.

③ R5 – comparison of engine length [mm]





However, the piston also needs to be weight-optimised and be designed to withstand the occurring loads. The piston developed by Mahle, featuring asymmetric shafts on the pressure and counter-pressure sides and sloping chamber walls, enables the strength and weight targets to be achieved. The 2.5 l turbo marks the first production implementation of this design concept.

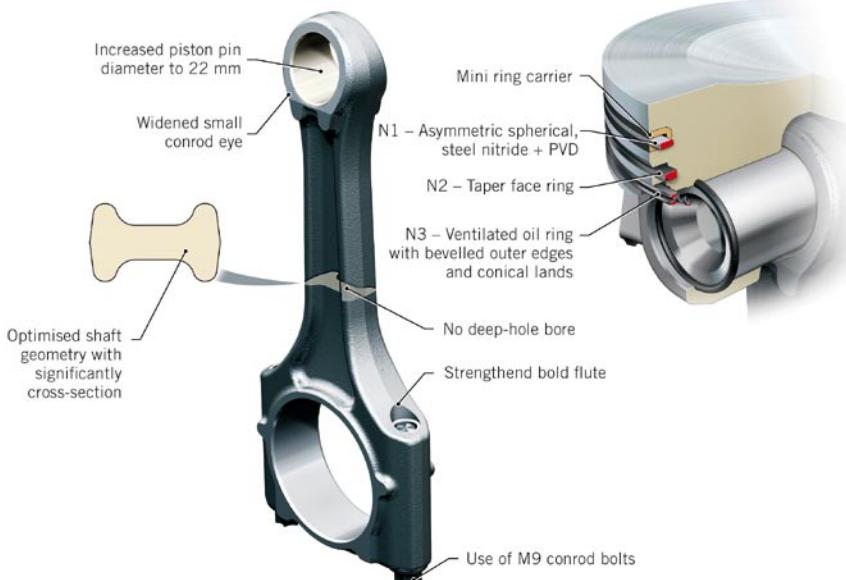
The first piston ring groove features an asymmetric spherical nitride steel ring with a PVD coating and inside bevel. The second and third grooves feature a taper face ring as well as the ventilated oil ring with bevelled outer edges and chromated

conical lands already fitted in other engine designs, ⑤.

The conrod is a forged cracked rod with no deep-hole bore. The pin diameter at the small eye is 22 mm and the bearing materials used are lead-free. The conrod was substantially strengthened for use in the R5 TFSI. ⑥ shows the measures implemented on the conrod.

The basis of the four-valve cylinder head with rocker arm valve drive is the 2.5 MPI engine, to which the following key modifications were made:

- : use of primary alloy ALSi7MgCu
- : deep-drawn water jacket around the spark plug



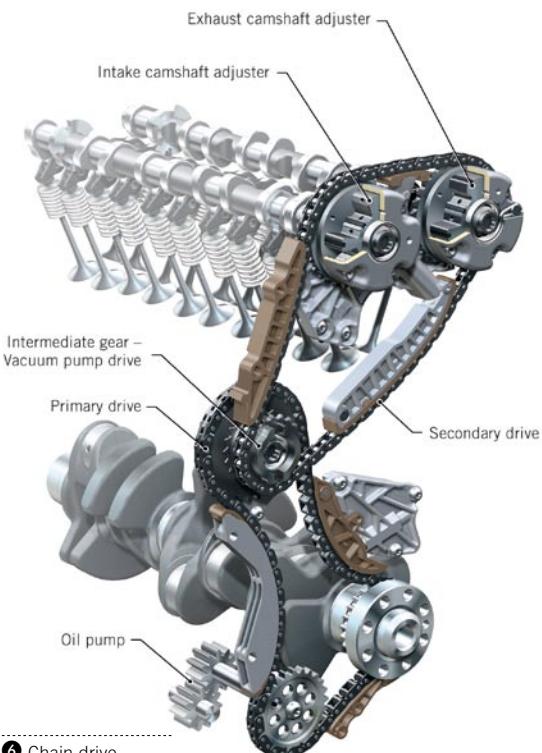
**⑤ Conrod and piston with mini ring carrier**

- : wear-optimised material at the exhaust seat ring
- : high-pressure pump ladder frame mounting
- : optimised exhaust cam contour
- : additional exhaust camshaft adjuster. The timing drive on the gearbox side is of two-stage design, and is driven by two different chain types, ⑥.

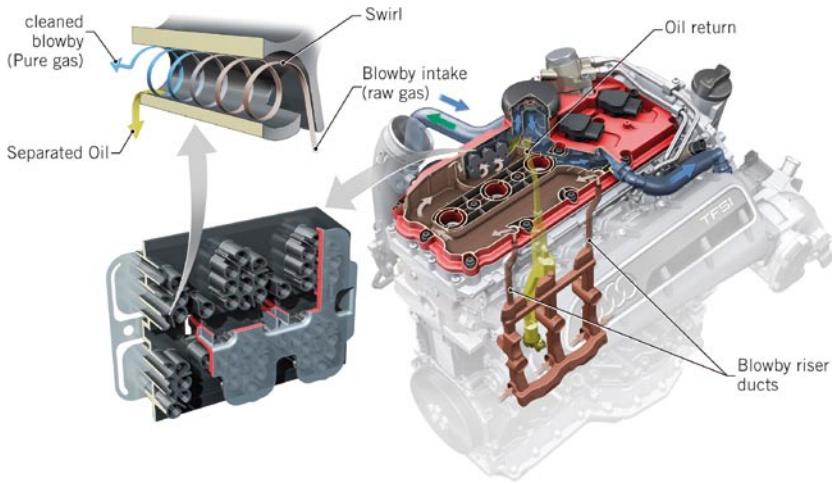
The geared-down oil pump is integrated into the primary drive. Both camshafts are driven by an intermediate gear which also drives the vacuum pump. Both drives are fitted with hydraulically damped chain tensioners. The chain used in the primary drive is a 3/8" toothed chain providing optimum acoustics.

The secondary drive features a 3/8" roller chain. The chain drive is lubricated by the return oil flow of the two camshaft adjusters and by a hole in the high-pressure chamber of the very soft-set secondary drive chain tensioner.

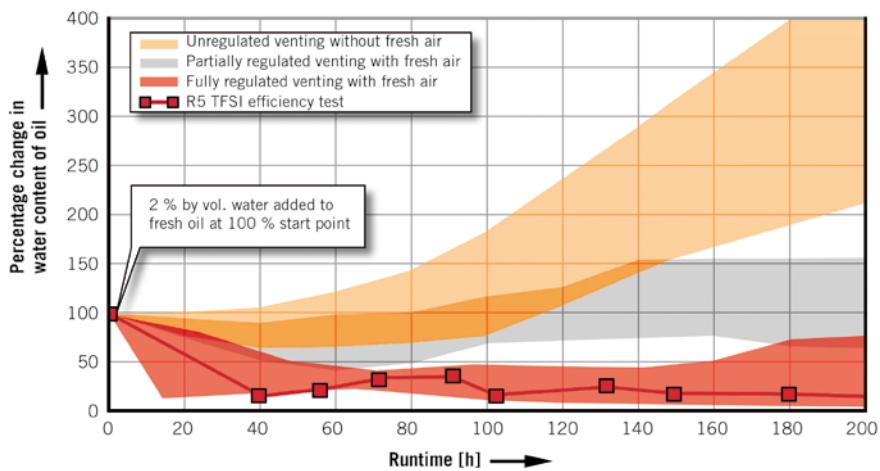
The ventilation system is an entirely overhead design. In developing the system, attention was paid to ensuring complete separation of oil-carrying and gas-carrying ducts. The tapping points in the engine block are protected in the bearing block of main bearings 2, 3 and 4, and are routed directly into the cylinder head



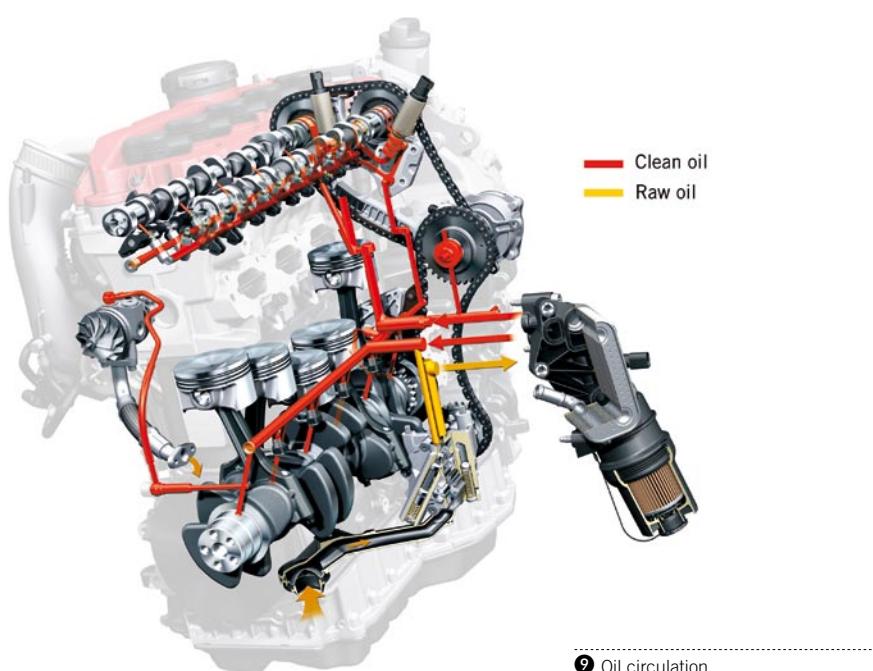
**⑥ Chain drive**



7 Crankcase ventilation system



8 Result from water discharge test



9 Oil circulation

cover, 7. An oil windage tray is built into the top section of the oil sump as a shield. The oil return flows are introduced below the oil surface level.

The gas introduced into the cylinder head cover is routed by way of a large cross-section to the fine oil separator. The fine oil separator is designed as a centrifugal separation system (Polylswirl).

The continuous return flow of oil from the fine oil separator is introduced below the oil surface level. In extreme cases, such as when iced-up or in the event of a malfunction, the ventilation system is protected against excessive pressure by a non-return valve built into the top of the oil sump.

The single-stage pressure regulating valve is built into the cover. The differential pressure-optimised non-return valves (against the intake manifold and the turbocharger side) in conjunction with the pressure regulating valve ensure the required negative pressure is maintained in the crankcase. The engine also features a PCV (Positive Crankcase Ventilation) system, which flushes through the engine with fresh air in the partial-load range. The gas-tight isolation between the blowby channels, the cylinder head cover and the depressurised oil chamber permitted the cylinder head to be used as the fresh air inlet. As a result, the entire interior of the engine is flushed out, sludging in the oil sump is prevented, and water discharge is significantly improved, 8.

The oil circulation system is essentially the one used in the R5 MPI induction engine, 9. For the turbo application, the oil sump was modified to integrate a thermal oil level gauge and the oil quantity was optimised in line with the high lateral and longitudinal acceleration of a sports engine. To that end, the oil pump intake line was optimised to provide adequate protection against air induction while maintaining high vehicle dynamism. The consumers specific to a turbo engine – the turbocharger, exhaust camshaft adjuster and high-pressure pump roller tappet lubricating nozzle – could be covered by the existing system.

The design of the intake system focussed primarily on high efficiency and throughput. With maximum air throughput rates of up to 1000 kg/h, the maximum possible cross-sections within the installation space were utilised and the

shortest and most direct possible air routing was achieved.

The fresh gas side essentially comprises the following assemblies, ⑩:

- : cold air intake including water separator, connection to front end
- : air filter with pulsation damping
- : compressor intake system with wastegate feed
- : compressor
- : pressure pipe upstream of charge air cooler
- : charge air cooler with plastic boxes
- : pressure pipe and throttle valve assembly with integrated wastegate valve
- : intake manifold with tumble flap system.

As well as optimising these particular assemblies, another aim was to optimise the flow to the compressor wheel on the intake side. Optimisation of the intake system by means of CFD delivered a flow control system enabling stable operation close to the compressor's pump limit, ⑪.

By being installed in the lower part of the front end, ⑩, the charge air cooler could be moved entirely into the ram pressure range. This enabled the external charge cooling air mass flow to be maximised, which delivered degrees of freedom in the inner lamination. Despite the internal flow derestriction which this provided, resulting in a pressure loss from the entire system of just 135 mbar at maximum throughput, cooling efficiencies of > 80 % were achieved at full load.

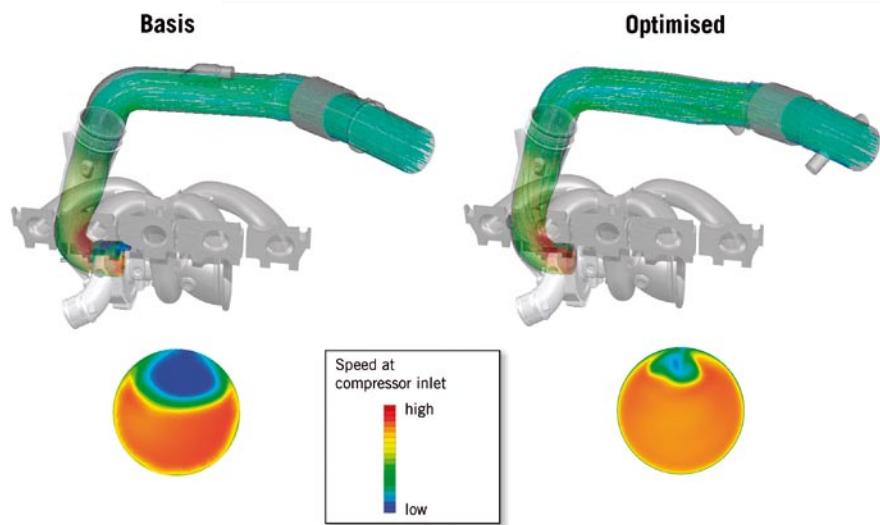
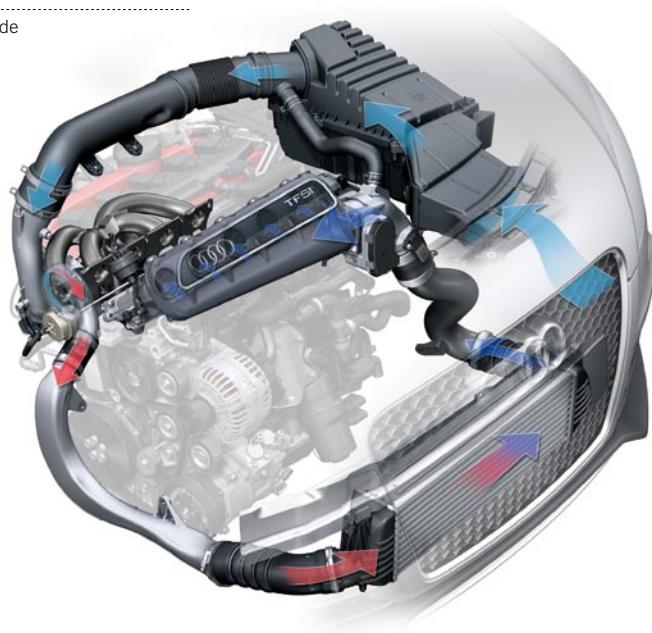
The intake manifold is designed as a two-part low-pressure sand-cast component comprising the intake arm gallery and the air collector. The pneumatic flap system built into the intake arm gallery, in conjunction with the tumble inlet duct, provides the necessary charge motion for optimum mixture homogenisation, ⑫.

The exhaust side comprises the following assemblies:

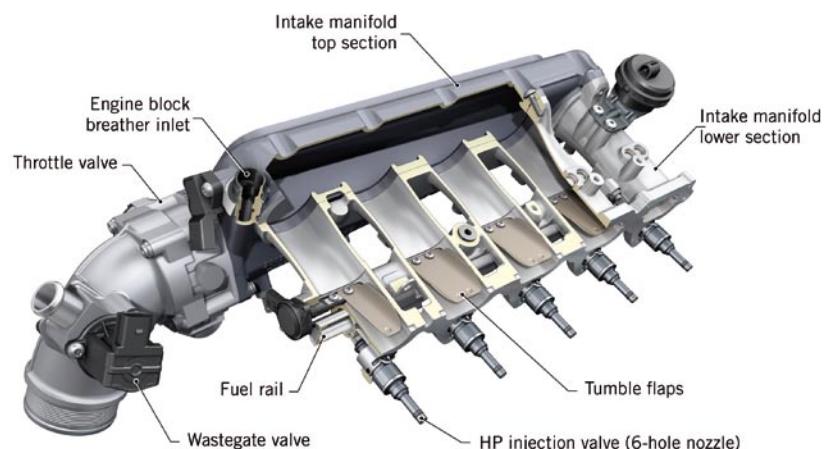
- : manifold/turbocharger module
- : close-coupled pre-catalyst
- : dual-flow front exhaust pipe with isolating elements
- : two underbody catalytic converters with downstream centre silencers
- : end silencer with two tailpipes.

The design of the manifold/turbocharger module was intended to embody the experience gathered from the Audi four-cylinder TFSI engines in production since 2004. After extensive testing of the flow control and load cycles, the "additional"

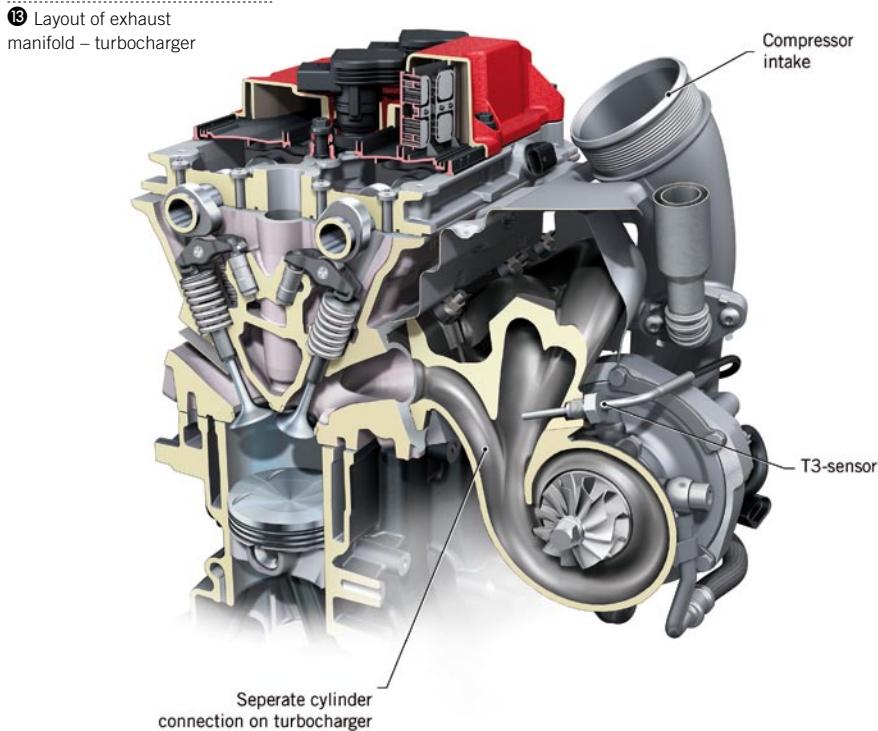
⑩ Overview of fresh gas side



⑪ Flow to compressor wheel



⑫ Intake manifold with tumble flaps



cylinder was integrated as a “separate feed”, 13.

The manifold/turbocharger module made of 1.48.49 grade cast steel is attached to the cylinder head by Audi's tried and tested clamp flange system. This, together with the unsupported construction of the turbocharger module, permits thermal expansion during operation, so enabling the introduction of constraining forces to be minimised.

The water-cooled turbocharger used – a K16 model from Borg Warner Turbo Systems – is characterised by high efficiency across a wide operating range. Compliance with the maximum permissible exhaust gas temperature of 980 °C is assured under all operating conditions by a sensor-based exhaust gas temperature control system.

One of the key areas of focus in development of the exhaust system was on minimising the exhaust gas counter-pres-

sure. The maximised pipe cross-sections necessary for this demanded the use of internal high-pressure formed pipes, as well as a dual-flow design in the vicinity of the propshaft, 14.

Reliable conformance to the EU5 emissions standard is assured by the close-coupled ceramic catalytic converters in conjunction with the two underbody metal catalysts.

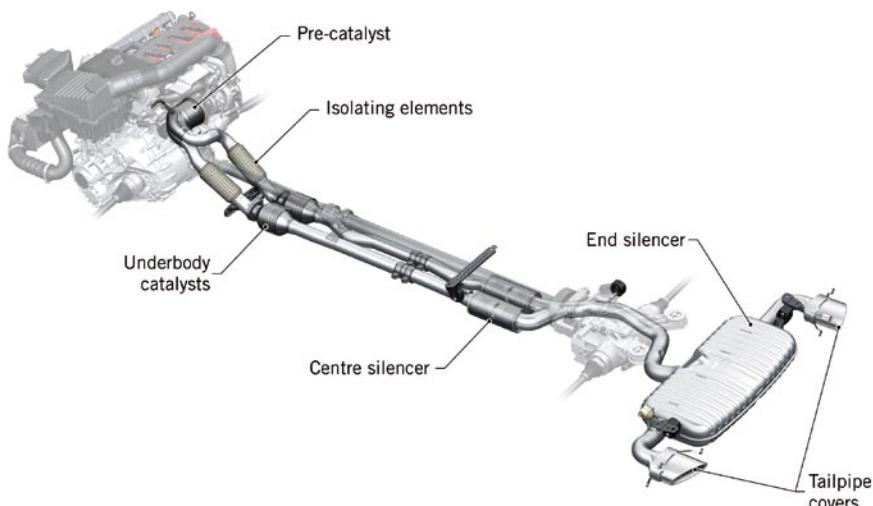
In the downstream exhaust system there are two centre silencers and one large end silencer. The exhaust gas mass flow through the left side tailpipe is switched by a flap. This provides for the typically sporty five-cylinder sound, as is familiar from the original Audi quattro.

The central element of the fuel system is a demand-controlled single-piston high pressure pump as was already fitted in the Audi V10 TFSI. The pump is driven by a triple cam fixed to the exhaust camshaft. By careful adjustment of volumes in conjunction with the high pressure pump control, the maximum 120 bar high-pressure system can deliver the rapid pressure build-up necessary for high-pressure starting down to ambient temperatures of -26 °C.

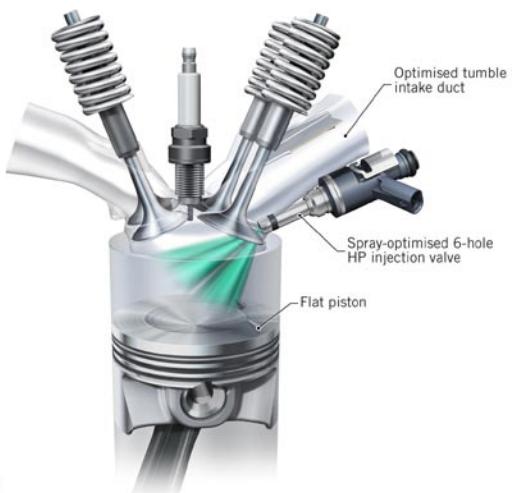
### THERMODYNAMICS

The targeted goal of delivering the widest possible usable revs range, at a high mean pressure level, with a power output of over 100 kW per litre, places extreme demands on the combustion process.

The model on which the development work was based was the Audi 2.0 TFSI



14 Exhaust system specific to the TT RS



15 Diagram of combustion process

engine. Like this unit, the 2.5 TFSI engine utilises the known benefits of the multi-hole valve technique ⑯. Optimisation of the spray parameters, in conjunction with the new flat piston head shape, enabled the mixture preparation process to be improved despite the app. 25 % higher flow rate of the high-pressure injectors compared to the 2.0 TFSI.

In order to attain the targeted values, it was necessary to tune the individual systems while at the same time paying attention to the mutual effects of the respective systems. Careful detailing enabled the individual revs ranges to be optimally tuned [3].

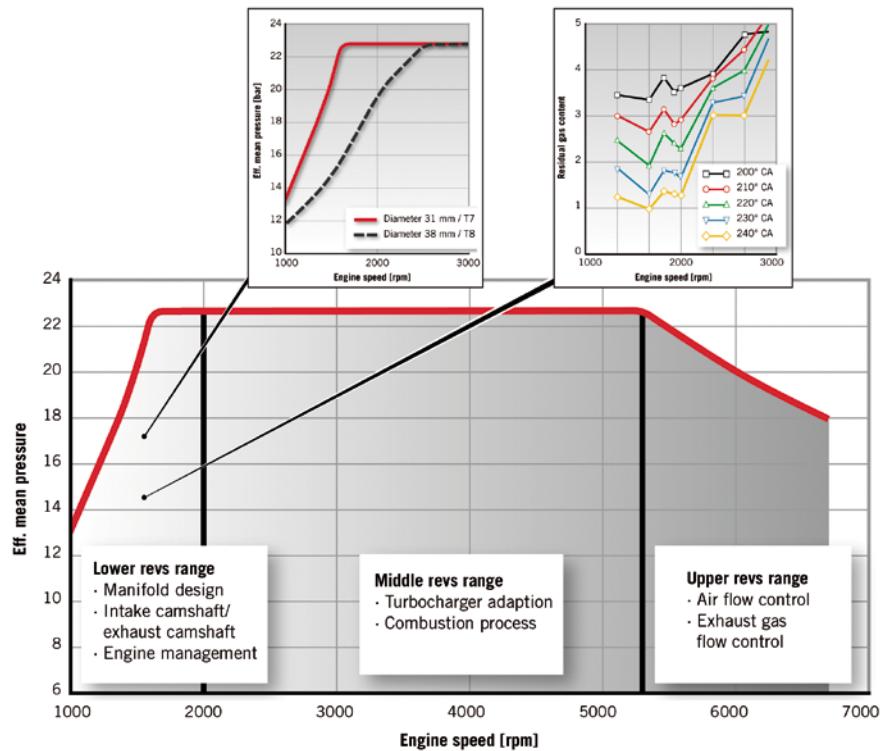
In the lower revs range, the separation of load reversal and mixture preparation, in conjunction with adjustment of the intake and exhaust camshafts, adaptation of the timing and event lengths, deliver major potential for minimising residual gas based on high flush rates, ⑯.

The required high charge levels at the lowest revs demand the generation of adequate turbine power with low exhaust gas mass flows. Optimum translation of the exhaust pulsations onto the turbine wheel was achieved by adapting the manifold and turbine cross-sections based on analysis of the stuffing behaviour at the nominal power point. The 31 mm diameter manifold arms feed into a 7 cm<sup>2</sup> turbine neck.

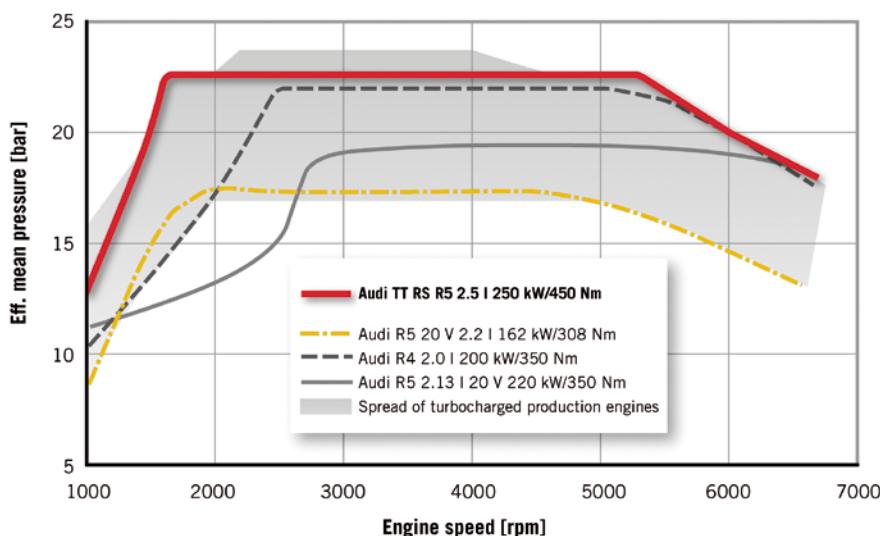
The low residual gas content, good mixture homogenisation and the resultant low tendency to knocking provide a very high compression ratio for this level of turbocharging of 10:1 (RON 98 rating), which substantially improves the mean pressure level in the lower revs range.

The selection of a relatively large turbocharger, attuned to the system and with very good efficiency levels, in conjunction with the efficient Audi combustion process and the high basic compression ratio, means the high mean pressure level can be maintained with very good thermodynamic characteristics in the middle revs range.

The entire system is optimised for maximum throughputs attuned to the upper revs range of this high-performance engine. The key factors in this are the carefully coordinated, pressure loss-optimised intake, pressure and exhaust systems.



⑯ Torque development parameters



⑰ Comparison across spread of turbocharged production engines

Conformance to the emission limits set out in the EU5 standard was attained by means of

- : a tumble flap intake manifold
- : multi-hole injectors in conjunction with a flat piston
- : a close-coupled primary catalytic converter.

Combined with appropriate fuel injection and catalytic converter heating strategies.

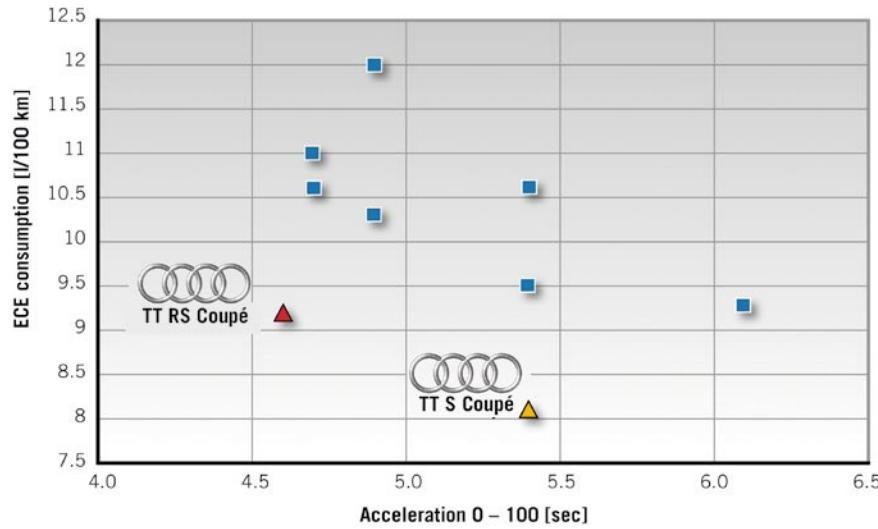
No secondary air injection system was required.

The maximum power output of 250 kW between 5400 rpm and 6500 rpm is matched by an impressive maximum torque of 450 Nm between 1600 and 5300 rpm.

⑰ shows the five-cylinder engine range compared to the spread of current competitors. The broad revs range at a high mean pressure level is clearly shown.

AUDI TT RS COUPÉ	250 KW/450 NM	
START-OFF ACCELERATION		
0 – 100 km/h	4.6 s	
0 – 200 km/h	15.9 s	
ELASTICITY	80 – 120 KM/H	
5th gear	5.1 s	
6th gear	5.9 s	

18 Performance table – Audi TT RS



19 Performance and fuel consumption compared to competitors

## DRIVING EXPERIENCE

The torque delivered by the five-cylinder engine in conjunction with an optimally adapted six-speed manual gearbox provides for outstanding acceleration and elasticity in the Audi TT RS, 18.

Despite this performance, fuel economy is also possible. The ECE consumption of the TT RS Coupé is a very low 9.2 litres per 100 km ( $\text{CO}_2$ : 213 g/km).

In everyday driving, employing a cautious driving style, consumption of well under 9 litres per 100 km is possible.

The following diagram shows the result in terms of performance and fuel economy compared to competitor sports cars, 19.

Here, too, the R5 engine achieves a new best mark. The specially attuned engine sound also contributes to the overall driving experience. The typical five-cylinder sound is pleasingly delivered through the intake and exhaust system at full throttle. At a constant speed and under moderate acceleration, the focus was placed on delivering a low, more restrained, sound.

## SUMMARY AND OUTLOOK

With the new 2.5 TFSI, Audi is building on its tradition in five-cylinder turbo engines.

The power unit, developed in a joint project by Audi AG and quattro GmbH, is the top-of-the-range engine option for the Audi TT RS.

Concerted utilisation of the potential offered by turbocharging technology, direct fuel injection, intake and exhaust camshaft timing adjustment, and careful tuning of the intake and exhaust sides, has produced a high-performance power unit featuring a wide usable revs range at a high mean pressure level.

The engine delivers sports car performance and driving enjoyment allied to reasonable fuel economy and  $\text{CO}_2$  emissions.

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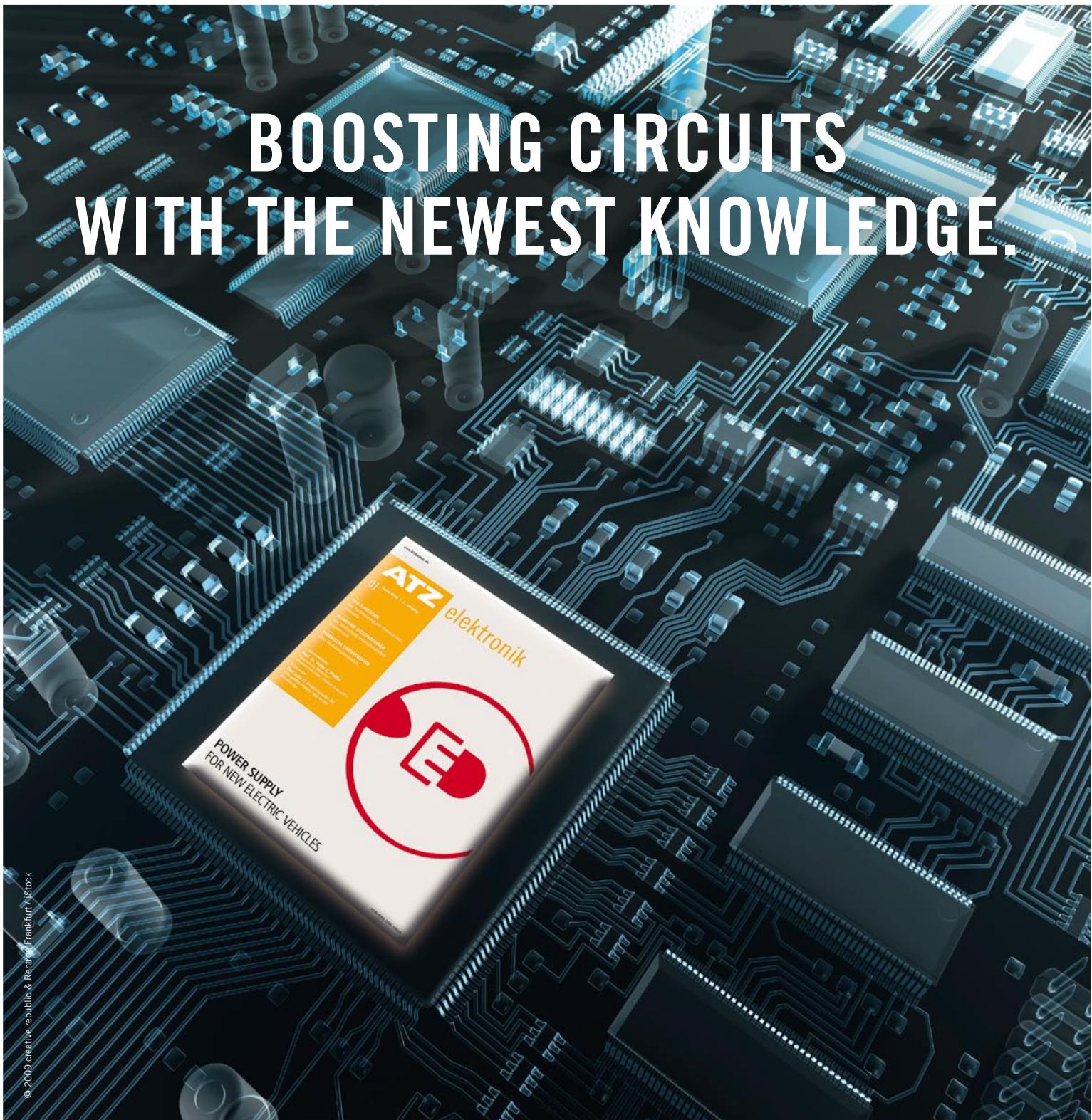
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