Abstract

Audi’s next generation 3.0 l V6 TDI engine once again marks a milestone in TDI technology.

The newly developed engine range combines low fuel consumption and emissions with outstanding performance, backed by the through-going application of light-weight construction technology.

Efficiency has been improved by optimising the intelligent thermal management system, the internal friction and the combustion process. Updating to a high-efficiency close-coupled emissions control system entailed further extensive modifications to the basic engine.

The new power unit thus delivers outstanding performance and high levels of comfort allied to very low fuel consumption.
Kurzfassung

Audi setzt mit der nächsten Generation des 3,0 l V6-TDI-Motors erneut einen Meilenstein in der TDI-Technologie.

Die neu entwickelte Motorenfamilie kombiniert niedrigen Kraftstoffverbrauch und geringe Emissionen mit exzellenter Leistungsentfaltung und konsequentem Leichtbau.

Zur Effizienzsteigerung wurden Optimierungen im Bereich des intelligenten Thermomanagements, der inneren Reibung und des Brennverfahrens umgesetzt. Der Umstieg auf eine hochwirksame motornah Abgasnachbehandlung bedingte weitere umfangreiche Änderungen am Grundmotor.

Mit dem neuen Aggregat ergeben sich somit exzellente Fahrleistungen und hoher Komfort bei sehr niedrigem Kraftstoffverbrauch.
1 Introduction

In 1989 car diesel engines underwent a revolution: the TDI from Audi. The direct injection turbodiesel unit set a new benchmark, being sporty, comfortable and economical in equal measure [1].

It was 25 years ago that Audi put into production this world’s first TDI engine – a 2.5 l R5 TDI unit with direct fuel injection, exhaust gas turbocharging and charge air cooling, and that fuel injection process was to become the basis of all modern-day diesel engines [2].

The world’s first V6 TDI engine for cars followed in 1997. The 2.5 litre unit featuring a distributor-type injection pump was the first four-valve TDI engine.

In early 2004 the first V6 TDI engine with Common Rail fuel injection and 3.0 litre capacity was launched. That engine also represented the first time a V6 TDI was offered as a Clean Diesel variant in North America.

In 2010 came the fully redeveloped second generation of the 3.0 l V6 TDI engine featuring innovative lightweight construction.

Today the V6 TDI engine is a market success not only for Audi but also for Volkswagen and Porsche. More than 2.3 million V6 TDI engines have been produced to date.

The next generation of the 3.0 l V6 TDI engine represents a systematic enhancement of the successful V TDI family in terms of power output, emissions and fuel efficiency.

The variants of the new engine generation are offered

- with power outputs ranging from 160 kW to 200 kW
- with maximum torque from 400 Nm to 600 Nm
- in the EU6 emissions class and in the EU5 and ULEV125 emissions class for export markets.

The market launch is scheduled for 2014 with the 200 kW EU6 variant in the new Audi A6/A7 model range.

Figure 1 shows the new compact V6 TDI engine from Audi.
Figure 1: The new Audi 3.0 l V6 TDI engine
2 Development goals

The key development objectives of the new V6 TDI engine generation, in line with Audi’s high quality standards, are set out in Figure 2.

Highlights alongside the main development objectives

- Low fuel consumption
- Low emissions to the EU6, EU5 and ULEV125 standards
- High engine output
- High torque
- Spontaneous power development
- High comfort

are the new engine family’s fulfilment of requirements relating to modular construction, with a maximum number of

- Identical components
- Synergy components

for all engine variants across all

- On-board systems
- Power classes
- Emissions classes.

These ambitious goals could only be achieved by implementing state-of-the-art diesel technologies.
Figure 2: The key development objectives

Figure 3 shows the main variants of the new modular V6 TDI engine family.

Figure 3: Power and emissions standard variants

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3 Description of the engine

Figure 4 shows the main dimensions and characteristic data of the new V6 TDI engine family.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Unit</th>
<th>Description</th>
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<tbody>
<tr>
<td>Layout</td>
<td>--</td>
<td>V6 engine with 90° V angle</td>
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<tr>
<td>Capacity</td>
<td>cm³</td>
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<tr>
<td>Stroke</td>
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<td>Bore</td>
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<td>Compression ratio</td>
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<td>16.0:1 (EU6)</td>
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<td>Distance between cylinders</td>
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<tr>
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</tr>
<tr>
<td>Inlet valve diameter</td>
<td>mm</td>
<td>27.5 (2x)</td>
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<tr>
<td>Exhaust valve diameter</td>
<td>mm</td>
<td>25.5 (2x)</td>
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<td>Fuel injection system</td>
<td>--</td>
<td>Common Rail, 2000 bar (Bosch CRS 3.20) with piezo-injector and high-pressure pump CP4.2</td>
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<tr>
<td>Turbocharger</td>
<td></td>
<td>GTD 2060 VZ with variable turbine geometry, electronic adjuster</td>
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<tr>
<td>Ignition sequence</td>
<td>--</td>
<td>1,4,3,6,2,5</td>
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<td>Nominal power output</td>
<td>kW</td>
<td>up to 200 kW at 4000 rpm</td>
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<tr>
<td>Torque</td>
<td>Nm</td>
<td>up to 600 Nm from 1500 – 3000 rpm</td>
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<td>Emission standard</td>
<td>--</td>
<td>EU5 / EU6 / ULEV125</td>
</tr>
<tr>
<td>Weight as per DIN 70020 GZ</td>
<td>kg</td>
<td>192</td>
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<tr>
<td>Motor length</td>
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Figure 4: Technical data of the new V6 TDI engine generation
3.1 Engine block and power train

The sand-core package cast engine block made of GJV450 split in the middle of the crankshaft has been comprehensively revised for the new V6 TDI.

It has been made 1.1 kg lighter than its predecessor by reducing the wall thicknesses and shortening the cylinder liner in the BDC zone.

The volume of the water jacket has been reduced by 0.4 litres by shortening and slimming-down measures which, thanks to the split cooling, results in even faster warming up after a cold start, with coolant standing in the block. Other measures to optimise the thermal management system of the new V6 TDI engine are detailed in Chapter 3.9.

The cylinder liners are plate-honed in order to attain an optimum cylinder shape in motorised mode. This technique is key to achieving a substantial reduction in piston ring pre-tension.

Figure 5 shows the engine block and power train of the new V6 TDI.
The crankshaft forged from 42CrMoS4 features a 30° split pin in order to attain equal ignition intervals. The main bearing and crank pins are inductively hardened to improve strength. The omission of the central counterweights and relief bores on all crank pins demonstrate the systematic application of lightweight construction technology here too. To cut manufacturing time, the 8-bolt fastening of the elastomer vibration damper on the front end of the crankshaft has been modified into a Hirth joint with just one central bolt.

To improve friction resistance and strength, for the 200 kW EU6 variant the aluminium piston with a salt-core cooling duct takes the form of a bush piston with a DLC-coated pin (see Figure 6).

![Bush piston](image)

Figure 6: Bush piston

In conjunction with an entirely newly developed ring package, with tangential tension reduced by more than 25 %, this significantly reduces friction in the power train by as much as 10 % (see Figure 7). To achieve reductions of this magnitude in ring pre-tension without compromising on wear, oil consumption and blow-by, the ring design had to be fully revised. Alongside a significant reduction in ring heights, the coating system features for the first time a combination of PVD (Physical Vapour Deposition) and DLC (Diamond-Like Carbon).
Figure 7: Comparison of power train friction torque with predecessor
3.2 Chain drive

One of the key requirements for the new V6 TDI engine family was to integrate close-coupled exhaust gas aftertreatment so as to improve its light-off performance based on fast heat-up.

The oxidation catalytic converter volume has been increased by 60%; flanged coaxially onto the turbine outlet of the turbocharger; space had to be created for it in the rear inner V area (see Figure 8). For that purpose, the layout of the timing drive, still located on the flywheel side, was completely changed (see Figure 9).

Figure 8: Modified timing drive to integrate close-coupled exhaust gas aftertreatment
The predecessor engine’s oil and Common Rail high-pressure pump drive located in one chain track have been functionally separated with a view to higher dynamic requirements in the future (potential for higher injection pressures and increased high-pressure pump strokes). The chain drive for the high-pressure pump, which is subject to dynamically high stresses, now takes the form of a torsionally rigid two-shaft drive, reliably avoiding resonance and thus high chain forces over the entire rpm range.

The drive for the oil/vacuum tandem pump flanged into the oil sump is now provided by a dedicated chain track directly from the front end of the crankshaft. This means the predecessor engine’s additional bearing point in the oil sump is no longer required.

An intermediate gear wheel mounted in the cylinder head to effect the 2:1 transmission ratio enabled the large camshaft sprockets to be omitted (see Figure 10). Operating from that intermediate gear, the camshaft drive is provided by a downstream double gear-wheel stage, with each gear wheel provided with tooth play compensation for acoustic reasons. To minimise friction in these additional bearing points, the intermediate gear mounting takes the form of a needle bearing.
Thanks to their greater robustness in terms of oil quality and different oil viscosities, the Audi V configuration diesel engines exclusively use bush chains with chrome-plated pins.

3.3 Cylinder head and valve gear

The increased demands imposed on the cylinder head in terms of power output and maximum cylinder pressure have been met by a complete redesign. The key features are an axle-parallel, symmetrical valve star and a two-part water jacket.

The two-part water jacket design already tried and proven in the V6 TDI Biturbo has been systematically enhanced and is now employed in all engine variants (see Figure 11).
Figure 11: Cylinder head with two-part water jacket

The lower water jacket ensures intensive cooling of the combustion chamber plate and the highly stressed valve webs thanks to very fast flow rates. Despite the increase in performance, the web temperatures have been reduced by as much as 25 K compared to the predecessor engine with a single-part water jacket (see Figure 12). The homogeneous temperature distribution means no cooling of the inlet valve web is required.

In the upper water jacket requiring less cooling, extremely slow flow rates prevail in order to minimise the water-side pressure losses.
The structure of the combustion chamber plate has been modified in the highly stressed web zones of the respective loading category.

In order to eliminate micro-notching effects in high loading zones, the geometry of the cooling ducts has been optimised, as has the parting burr characteristic of the inlet ducts. The objective was to prevent mould parting burrs from coming to rest in the maximum loading zone and to enable reliable automatic deburring of these.

A further feature of the new cylinder head is its extremely compact design, resulting among other factors from the omission of the previously cast-on inlet duct flange. In the new V6 TDI the inlet duct flange is replaced by a separate, lightweight component in PA6-GF35 (see Figure 13). In conjunction with other structural improvements, this makes both cylinder heads 2.5 kg lighter than in the predecessor engine. In addition, the virtually cubic outer geometry of the new cylinder head ensures outstanding machinability in production.
The ultra-light camshafts take the form of constructed hollow shafts and are mounted on separate double bearing covers. The bearing diameter has been reduced by 27% in order to cut down on friction.

The valves are actuated by newly designed extremely rigid rocker arms with larger rocker diameters than the predecessor model. In conjunction with a revolving rocker pin, this has greatly enhanced robustness, even at low oil viscosities.
3.4 Fuel injection system

The tried and proven fuel injection system with 2000 bar system pressure from the predecessor project has essentially been retained. Targeted improvements have enhanced the efficiency of the system so as to safely attain the development objectives for the new engine generation with regard to untreated emissions and engine power.

To increase the hydraulic pressure on the injector nozzle and so enhance the engine’s performance potential without impacting negatively on the untreated emissions potential of the fuel injection system, the throttle bore in the injector throttle plate has been enlarged by 20% (see Figure 14). This measure, retaining an unchanged nozzle flow rate, was one of the factors in boosting the performance of the new V6 TDI relative to its predecessor.

![Common Rail injector](image)

Figure 14: Common Rail injector

To further optimise untreated emissions for the ULEV125 variant, in view of its 200 kW lower power output than the EU6 variant, a nozzle with a reduced hydraulic flow rate is employed.

To increase the maximum power output of the new V6 TDI engine family as far as possible, the hydraulic delivery volume of the Common Rail high-pressure pump has been increased by increasing the stroke.

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The selected configurations enable compliance with emissions standards while maximising fuel economy and spontaneous torque development.

### 3.5 Air intake

The core component of the air intake system in the new V6 TDI is the intake manifold made of PA6-GF35 located in the inner V. The continuous dual-flow design permits load/speed-dependent swirl control with just one central swirl control flap.

To implement this complex geometry, the intake manifold consists of three single friction-welded shells. The cross-sections and geometry of the EGR intake in the upstream charge air pipe have been optimised in a series of calculation loops with regard to charge cycle and uniform distribution.

All in all, this has resulted in an air intake system which has been optimised in terms of functionality, weight and manufacturing cost (see Figure 15).

![Figure 15: Air intake](image-url)
3.6 Exhaust gas recirculation

The exhaust gas recirculation system, with a single-stage EGR cooler for the EU5/EU6 variants and a two-stage cooler for the ULEV125 variant, is of modular design (see Figure 16). This means the main cooler can be installed with the same geometric form with a pneumatic EGR bypass valve and an electric EGR valve in both configurations.

In the ULEV125 application this main cooler is supplemented by a pre-cooler with an additional pneumatic bypass valve.

Figure 16: Modular EGR system
The two modular variants enable the conflicting goals of cooling power and pressure loss of the EGR system to be optimally met for the respective application within the available space. In the ULEV125 configuration, this means that four EGR bypass switching states with different cooling power levels can be selected as needed.

3.7 Exhaust manifold and turbocharger

The exhaust manifold has an air gap-insulated outer shell. The inner pipes are fabricated by hydroforming. The weight has been reduced by 20% thanks to a weight-optimised flange to the cylinder head with eight bolting points instead of seven and based on the use of V-shaped ribbon clips to fasten the two manifolds on the turbocharger (see Figure 17).

Figure 17: Hot side
The new V6 TDI engine family marks the launch of a new turbocharger generation (see Figure 18).

The key features of this new generation are reduced play of the VTG (Variable Turbine Geometry) and a reduction of flow-impeded cross-sections in the turbine. A major factor in this is the use of a riveted VTG cartridge which is of a much more flow-enhancing design than the casting with cast joining elements familiar from the previous generation (see Figure 19).
The configuration for the new V6 TDI thus enables engine power outputs ranging from 160 to 200 kW with just one turbocharger variant which delivers optimum engine responsiveness and thus a marked improvement in driving dynamics in all applications.
3.8 Oil circuit

A fully variable oil pump is employed for the first time in an Audi V configuration TDI engine.

The vane pump, continuously controlled by way of an eccentric ring, permits optimum adaptation of the pressure/volume flow depending on load and engine speed. Figure 20 shows the control range of the oil pump at an oil temperature of 90 °C. In the chart, 100 % corresponds to the maximum oil pressure occurring in the system. Up to 60 % is fully variable on demand.

Additionally, the throughput of the piston jets can be influenced, or shut off, by way of the pressure map.

All in all, this improves consumption by approximately 2 g CO₂/km in the NEDC.

![Figure 20: Fully variable oil pressure](image)
An oil thermostat, consisting of a wax expansion element with a sliding sleeve integrated into the pressurised oil gallery of the engine block provides a thermostatically controlled oil cooler bypass, thereby ensuring rapid warming up of the oil after a cold start or maximum oil cooling depending on the requirement (see Figure 21).

**Figure 21:** Thermostatically controlled oil cooler bypass
3.9 **Coolant circuit and thermal management**

The tried and proven design concept of the predecessor engine featuring separate head/block cooling (split cooling) has been retained and optimised further (see Figure 22). This optimisation focused on reducing pressure loss and on further accelerating the warming up of the block after a cold start (see Chapter 3.1).

![Figure 22: Coolant circuit](image)

The innovative thermal management concept permits autonomous supply to the interior and gearbox oil heating via the cylinder head circuit, regardless of the coolant standing in the engine block. As a result, it improves consumption in all engine running modes of relevance to customers.

Coolant flows through the engine block and cylinder heads in two parallel cooling circuits. The water pump located in the inner V now has a covered impeller with three-dimensionally curved blades, and continuously supplies the two sub-circuits.
**Cylinder head circuit**

The continuous-flow cylinder head circuit primarily consists of the water chambers of the two cylinder heads and the oil and EGR coolers, plus the vehicle-side heating and gear oil heat exchangers and the main water cooler.

The temperature level of this circuit is regulated by a newly developed mapped thermostat with a ball valve (see Figure 23). Thanks to its virtually free cross-section, the fully open ball valve significantly reduces pressure losses compared to a conventional plate thermostat.

**Engine block circuit**

The coolant standing in the block after a cold start is presented via a vacuum-controlled rotary slide valve seated in the inner V.

The modified integration of the rotary slide valve into the block circuit prevents any coolant flow – and the associated unwanted heat discharge – when the valve is closed. As a result, the non-return valves in the predecessor engine are no longer required, reducing pressure loss by as much as 75 % when the valve is fully open.

When operating temperature has been reached, the coolant temperature in the engine block circuit is regulated by the ball valve to approximately 105 °C in order to reduce friction loss in the part-load range.
Figure 23: Mapped thermostat with ball valve

Water pump

Ball valve (open)
Heatable wax expansion element

Ball valve (closed)
4 Exhaust gas aftertreatment

Without exhaust gas aftertreatment, it would not be possible to comply with globally tightened emissions standards. Consequently, the design of the exhaust system for the new V6 TDI was integral to the development of the new engine family.

As already described in Chapter 3.2, the basic engine has been fundamentally modified for this purpose.

The key areas of focus in designing the exhaust system for the new generation of V6 TDI engines were:

- Minimal distance to turbocharger outlet, i.e. close-coupled: Earlier light-off thanks to reduced temperature losses
- Improved CO/HC performance and stable NO₂/NOₓ ratio over the running time
- Extended AdBlue mixing distance and use of a full-flow mixer: Optimum preparation of the metered AdBlue resulting in further improvement in NOₓ conversion rates while reducing NH₃ slip
- Enhancement of the SCR coating integrated on the highly porous DPF (SCR@DPF) [5] (see Figure 24)
- Modular, unified exhaust system for all future model series: Utilisation of synergies and reduction in complexity and cost

Figure 25 shows the exhaust gas aftertreatment system of the EU6 variants for the A6/A7 model ranges.

A slip catalytic converter is installed downstream of the oxidation catalytic converter/SCR@DPF unit which, with its combined coating comprising an SCR and oxidation catalyst, performs two functions. Firstly, the CO resulting from sooting is oxidised by the precious metal content of the coating to form CO₂ and, secondly, NH₃ slip is reliably eliminated.
Figure 24: Close-coupled exhaust gas aftertreatment with SCR@DPF

Figure 25: Exhaust system of the EU6 variants for the A6/A7 model ranges
4.1 Statutory requirements

Figure 26 shows the two stages of the current EU6 emissions standard.

The tightening of the NOₓ limit from 180 to 80 mg/km being implemented in 2014 will be supplemented by an RDE monitoring phase. RDE stands for Real Driving Emissions, meaning emissions in real driving in a wide variety of different conditions. This phase will run until 2017 with no binding limit. But data will be collected and published. A binding limit for RDE is expected as from 2017.

A mobile measurement unit – the so-called PEMS (Portable Emissions Measurement System) – measures RDE in real driving conditions. It is also planned to measure fuel consumption and CO₂ emissions for stage 2 in the more customer-oriented WLTP cycle.

4.2 AdBlue preparation and uniform distribution of ammonia

Close-coupled AdBlue metering poses a major challenge due to the restricted space.

A highly uniform distribution was attained despite the short mixing distance thanks to a spray with six jets instead of four and a spray angle of 25° in conjunction with an oval full-flow mixer.
The NO$_x$ emissions and the uniform distribution of NH$_3$ downstream of the SCR@DPF at 200 °C are shown by Figure 27. This test was based on hyperstoichiometric metering with a factor of 1.3. The NO$_x$ conversion rate and NH$_3$ distribution have been significantly improved compared to the predecessor project.

![Figure 27: NO$_x$ conversion rate and NH$_3$ distribution downstream of SCR@DPF at 200°C ($\alpha = 1.3$)](image)

Figure 28 shows the NO$_x$ stationary conversion rate and the NO$_2$ content in the NO$_x$ downstream of the oxidation catalytic converter plotted over the SCR@DPF inlet temperature for a fresh, furnace-aged system (oxidation catalytic converter: 800 °C, SCR@DPF: 850 °C, in each case 16 h and hydrothermal).

The comparatively hard furnace ageing of the SCR@DPF system at 850 °C reduces the NO$_x$ conversion rates at higher temperatures. The change in activity in the low temperature range results from the decreasing formation of NO$_2$ due to the ageing of the oxidation catalytic converter. Compliance with emissions limits is assured over the running time even with this decrease in NO$_x$ conversion rate.
4.3 Combination of SCR@DPF with NO\textsubscript{x} storage-type catalytic converter

The ambitious targets for CO\textsubscript{2} reduction down to well below 120 g/km result in a further lowering of the exhaust gas temperature. Consequently, further exhaust gas aftertreatment improvements are essential in addition to temperature-sustaining measures which are, as far as possible, CO\textsubscript{2}-neutral.

For especially critical applications, such as with underbody SCR systems, electrically heated oxidation catalytic converters (e-cats) are already in use today.

To achieve the best possible emissions performance while minimising the increase in CO\textsubscript{2}, the new V6 TDI engine generation combines the close-coupled SCR system with an NO\textsubscript{x} storage-type catalytic converter which replaces the oxidation catalytic converter. The abbreviation NOC stands for NO\textsubscript{x} Oxidation Catalyst.
This combination, applying an intelligent operating strategy, ideally combines the advantages of both exhaust gas aftertreatment systems:

- Optimum low-temperature activity of the NOX-storage
  Avoidance of heating measures (e.g. e-cat) which for purely SCR systems would be necessary below a certain CO₂ threshold
- Limitation of the enriched mode impacting on customers’ fuel efficiency, as the SCR system takes over the NOXconversion at medium temperatures
- Sustained high NOX conversion under high loads thanks to the SCR system

Figure 29 shows the interaction of the two systems.

At medium to high temperatures, nitrogen oxides are removed solely by conventional means via the SCR system, resulting in corresponding consumption of AdBlue. This is typically neutral in terms of fuel consumption, with the lowest CO₂. As the exhaust gas temperature falls, the NOC takes over the exhaust gas cleaning. AdBlue consumption decreases, while CO₂ increases slightly due to the enriched running mode then required. A specially developed NOC/SCR coordinator regulates the interaction to obtain the best possible emissions with a minimal rise in CO₂.
The responses of the exhaust gas aftertreatment system to the decreasing CO₂ emissions based on the example of EU6 V6 TDI development at Audi are summarised in Figure 30.

The first generation of the 3.0 l V6 TDI achieved its emissions targets entirely based on an SCR system located away from the engine in the vehicle underbody [3, 4]. Compliance with increasingly ambitious CO₂ targets is resulting in a significant lowering of exhaust gas temperature with every new engine and vehicle model generation. Consequently, the predecessor generation marked the transition to integration of the SCR coating in the DPF (SCR@DPF) [5]. The efficiency variants were additionally fitted with an e-cat. The close-coupled SCR@DPF system has been enhanced for the new V6 TDI engine family. Thanks to its higher overall performance, no e-cat is needed. CO₂-optimised variants such as the 160 kW model are in particular fitted with the combined NOC / SCR@DPF system.

Figure 30: Development of engine and exhaust gas aftertreatment technologies
5 Combustion process

The consistent and continual enhancement of the V6 TDI is also demonstrated by the combustion process. In addition to increasing power output to as much as 200 kW, particular attention was paid to reducing fuel consumption. To achieve this, the thermodynamics of the Audi 4-valve combustion process were fundamentally revised.

The focus of this work was on redesigning the inlet ducts in terms of swirl and flow rate, and on optimising flow in the exhaust ducts (see Figure 31). The result is a significant improvement in charging allied to a reduction in charge cycle losses. The modifications to the combustion process are rounded off by a widening of the piston cavity combined with a 0.8 unit lower compression ratio for the EU6 variants.

High combustion efficiency with a high emissions potential in terms of NOx/soot trade-off is the outcome of the modified combustion process.

In conjunction with the optimised turbocharger, an optimised inlet valve stroke curve, which particularly improves responsiveness from low engine speeds, markedly improves spontaneity and driving enjoyment.
Figure 31: Combustion process with optimised ducts
6 Power and emissions standards variants

The new V6 TDI engine family is offered in a number of variants (see Figure 3). The top and bottom of the range power outputs are the 160 kW and 200 kW EU6 variants. Between them are the EU5 and ULEV125 variants.

6.1 200 kW EU6 variant

Compared to the predecessor engine’s 180 kW in the A6/A7 for example, the top power output has been increased to 200 kW (see Figure 32).

The use of a fundamentally revised turbocharger has enabled the torque to be significantly increased down to the lowest engine speed range despite the increase in power output, resulting in an extraordinarily wide torque range. In the engine speed range from 1500 to 3000 rpm, a torque of up to 600 Nm can be offered depending on gearbox and vehicle application. Together with the more spontaneous charge pressure build-up compared to...
the predecessor engine and the power plateau up to more than 4000 rpm, this ensures a
dynamic performance and greater sportiness from the engine.

Key factors in enhancing the dynamics and power alongside the optimised turbocharger
are also the reduced friction loss in the basic power train (see Chapter 3.1) combined with
the optimised charge cycle. To achieve this, an optimised camshaft was installed and the
inlet ducts were optimised with regard to swirl and flow rate.

6.2 160 kW EU6 variant

The variant with 160 kW power output and torque of 400 to 500 Nm (depending on the
gearbox fitted) has been optimised in a number of aspects compared to the 200 kW unit
(including demand-based adaptation of the water pump and oil cooler) with a view to
improving consumption.

In order to improve efficiency, throttle losses have been minimised by reducing the swirl
control flap positioning angle over a large map range. This was made possible by a
substantial increase in basic swirl of the inlet ducts in order to maintain maximum
combustion efficiency.

The 160 kW power output permits the use of low-viscosity oil, which plays a key role in
reducing fuel consumption, particularly during warm-up.

A further measure is the power output-oriented setting of the exhaust valve timing and the
resulting more efficient utilisation of expansion work. This has enabled consumption to be
significantly reduced once again compared to the 200 kW unit.
6.3 EU5 variant

An EU5 variant of the V6 TDI engine is being developed for countries with a maximum permissible sulphur content in fuel of 500 ppm.

This variant is characterised by an increased geometric compression ratio, meeting demands relating to starting capability at altitude in conjunction with lower cetane numbers.

Specially for this variant, an exhaust gas aftertreatment system has been developed with an oxidation catalytic converter and diesel particulate filter featuring catalytic coatings which are highly resistant to sulphur, so as to attain permanent functionality of the active surfaces of the catalytic converters.

6.4 ULEV125 variant

As an enhancement of the successful predecessor engine in North America, an additional variant is being developed to comply with ULEV125 emissions targets.

In order to achieve this low emissions level, EGR cooling has been greatly boosted by the use of a pre-cooler to improve the NOx/soot trade-off up to the highest loads and engine speeds. The optimised reduced-flow piezo-injector delivers a further significant improvement of the NOx/soot trade-off.

To compensate between the different fuels in terms of cetane numbers, a cylinder pressure sensor is also employed. This means that combustion stability – and thus emissions control, fuel economy and acoustics – can be optimised even when using fuels with low cetane numbers.
7 Application

The steadily rising complexity in development of modern-day diesel engines also poses new challenges in terms of application. The combined exhaust gas aftertreatment with NOC and SCR@DPF in particular demands new functional approaches.

To cope with the wide variety of different operating states and switching operations, model-based air regulation was developed for the new engine family (see Figure 33). For this, the parameters relevant for the running of the engine, such as the EGR rate or cylinder charge, are calculated on the basis of the recorded sensor inputs (pressures, temperatures). In addition, the respective characteristics of the various actuators (turbocharger, EGR valve,…) are mapped in the control unit. This provides the basis for further development of model-based control structures.

The advantage, in addition to improved control quality, is that no complex coordination of control parameters according to the different environmental conditions and engine operating states is required. Moreover, a finished application can be transferred to other vehicle variants with comparatively little effort.

Figure 33: Complexity of model-based air regulation
8 Performance and fuel consumption

The new generation of the V6 TDI engine is being installed first in the new Audi A6/A7 model ranges. The 200 kW power version with S tronic and quattro drive will be available first (see Figure 34), followed by the 160 kW version.

In both cases Audi has succeeded in consistently enhancing the core product attributes of performance, fuel efficiency and comfort. At the same time, the models comply with the new EU6 emissions standard.

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<thead>
<tr>
<th></th>
<th>Audi A7 V6 TDI Predecessor</th>
<th>Audi A7 V6 TDI New generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>S tronic quattro</td>
<td>S tronic quattro</td>
</tr>
<tr>
<td>Emissions class</td>
<td>EU5</td>
<td>EU6</td>
</tr>
<tr>
<td>Max. torque</td>
<td>580 (Nm)</td>
<td>580</td>
</tr>
<tr>
<td>Max. power</td>
<td>180 (kW)</td>
<td>200</td>
</tr>
<tr>
<td>Acceleration 0 - 100 km/h</td>
<td>6.3</td>
<td>5.8</td>
</tr>
<tr>
<td>Top speed</td>
<td>250 (limited)</td>
<td>250 (limited)</td>
</tr>
</tbody>
</table>

Figure 34: Performance in the A7 compared to the predecessor

The new V6 TDI engine family has not only cut CO₂ emissions by a substantial double-figure percentage, it has also markedly enhanced engine power and performance. Both represent top values for a model of the upper executive segment.

They guarantee maximum efficiency and driving enjoyment in equal measure.
9 Summary

The newly developed V6 TDI engine generation offers outstanding power and torque of up to 200 kW and 600 Nm respectively. This results in top-class performance allied to excellent fuel economy.

Thanks to extensive modifications to the basic engine in conjunction with an innovative exhaust gas aftertreatment system incorporating the close-coupled SCR@DPF system and, for high-efficiency variants, combined with an NOC, the strict limits of global emissions standards are reliably met.

The modular design of the new V6 TDI engine family offers economical variants for all requirements based on extensive utilisation of synergies.

The new V6 TDI engine generation demonstrates that improved efficiency and enhanced performance and vehicle dynamics do not have to be mutually exclusive. Based on successful implementation of the development premise of exhaust gas aftertreatment as the core component of engine development, the new V6 TDI engine family has reconciled those apparently conflicting objectives.
Literature


