Introduction to Active Sound Management Technology

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Abstract

Active Sound Management is a technology that enables to control sound effectively leveraging the existing audio system. More recently, it has been expanding to be applied as a technology to provide in-cabin acoustic environment with comfort, such as eliminating uncomfortable low frequency "boom" sound resulting from powertrains and enhancing powerful engine sound.

In this article, the system developed by DENSO TEN, which includes the DSP with Active Sound Management algorithm by Müller BBM GmbH coded, is discussed. Based on the existing audio system, configuration parts added microphone, speaker, and others, system design requirement such as signal processing of CAN-BUS, and analysis of tuning results on actual vehicles (reduction of boom sound and enhancement of engine sound) are introduced.

1. Introduction

1.1 Active Sound Management Technology

Active Sound Management enables OEMs to control sound effectively, leveraging the existing audio system. It allows providing a wide range of acoustic options. For the past decade, Noise Vibration (NV) teams have used Active Sound Management to reduce driver fatigue by eliminating uncomfortable low frequency "boom" sound resulting from powertrains. More recently it is also used to create in-cabin acoustic brand images such as refined luxury, familiar comfort, and sporty excitement.

Active Sound Management software continuously creates appropriate constructive and destructive acoustic fields to enhance or create desired powertrain sounds and to reduce or eliminate unwanted powertrain sounds. This significantly reduces the reliance on expensive mechanical solutions such as tuned exhaust manifolds, waveguides, mufflers, and sound dampeners. Two aspects of Active Sound Management will be discussed below.

1.2 Active Noise Cancellation (ANC)

Loud engine/powertrain sounds can result from mass reduction of components that result in increased vibration. Uncomfortable sounds also result from early torque converter lock, cylinder deactivation, transition from electric to Internal Combustion Engine (ICE), as well as Continuously Variable Transmission (CVT) drivetrain. Technologies designed to improve fuel efficiency typically have a side effect of causing uncomfortable sounds and render the vehicle non-salable. ANC tool is to reduce these sounds and associated harmonics.

1.3 Engine Sound Enhancement (ESE)

One of the desired acoustic signatures to be enhanced is notes of powerful engines. ESE can change the acoustic sound signature of small fuel efficient, high RPM, high power engines to sound signature of older traditional large I5/V6/V8 engine sound with lots of modulated low rumbling bass notes. Uncomfortable sounds of 3 cylinder engine operation can be masked by creating familiar 4 or 6 cylinder engine sound signatures. For electric cars, this technology also allows us to create a pleasant sound character.

2. Outline of Active Sound Management

2.1 Structure of the System

Fig. 1 shows a simplified least mean square (LMS) system diagram. [Ref.1] The advantage for Active Sound Management in automotive is that the rotational speed (RPM) of various vehicle components are typically known to within 12 to 25ms period. This advantage allows targeting the engine and powertrain rotational sounds with low computational effort. The resulting software is therefore very lightweight and can be added to an infotainment or audio system CPU or DSP relatively easily. Typically, multiple ANC and ESE datasets operate concurrently and can seamlessly adapt and transition from cylinder deactivation, to various sports modes.

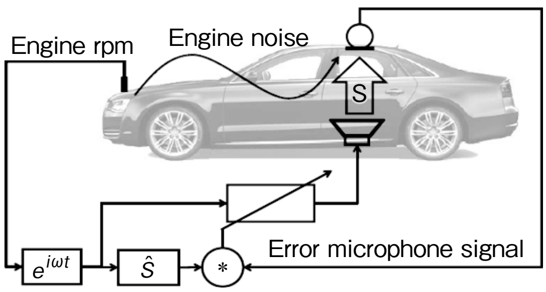

Fig. 1 Block Diagram of ANC and ESE

2.2 Components of the System: Microphones

Typical Active Sound Management application uses the existing vehicle audio system. Error feedback microphone (e-mic) is applied for ANC function and is not necessarily needed for ESE function. The e-mics used for ANC function have a very limited frequency response, typically only to 1 KHz. Therefore, ANC e-mics are inexpensive compared to telephony microphones.

The ANC frequency cancellation range is defined by distance of the e-mic from the occupants head location (e.g. ¼ wave 94cm = ˜90Hz). Therefore, a single e-mic in the center of the vehicle could provide large cancellation below 60Hz and taper off to minimal effect at 90Hz in all seats. Similarly a single e-mic placed directly over the driver position could provide large cancellation up to 240Hz and taper off at about 300Hz. MY18 and beyond it is common for OEMs to use 3 to 4 e-mics to create good cancellation effect for every seat, see **Fig. 2**.

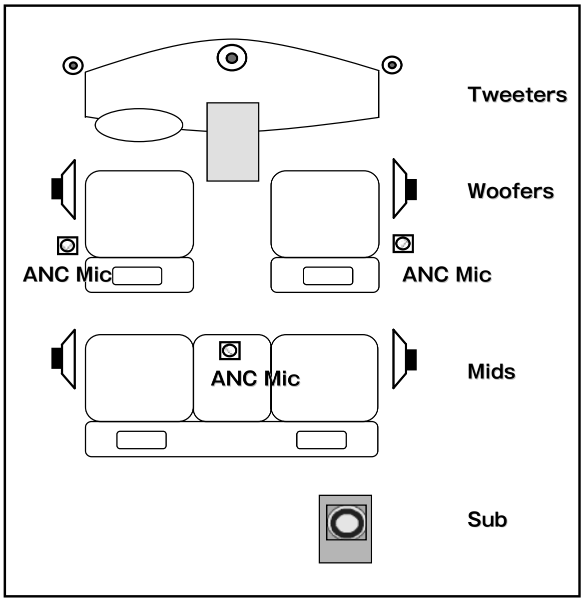

Fig. 2 Typical 3 error mic. system configuration

2.3 Components of the System: Speakers

The desired sound image determines Active Sound Management applications. Ideas such as filling in a 2dB notch to restore linearity to the engine sound, to cancelling over 20dB from 30-90Hz, to creating a roaring modulated sound of a powerful naturally aspirated engine.

While all vehicles can benefit from stock speakers, typically 1 to 6 speakers are actively driven in Active Sound Management applications; 4 speaker, plus 2 tweeter stock configurations being the most common, see **Fig. 2.** Usually, dedicated subwoofers are added to larger SUV applications where there is a need to cancel high levels of low frequency sound resulting as a side-effect of fuel efficient powertrains. High end sports cars also tend to have upgraded audio systems that allow for good low frequency extension for ESE application.

2.4 Components of the System: Signals

Active Sound Management is required to match the continuously varying RPM of the engine and powertrain. Any delay would cause undesired audio artifacts and ghost sounds. Therefore, the Active Sound Management system requires real-time response to powertrain signals.

ANC function requires RPM signal as input signal which can be either analog input or via CAN bus. ESE functions, in addition to RPM, also would need the torque, vehicle speed, and percent accelerator information. The RPM signal is used for frequency matching, whereas the other information is used to adjust the gain. Additional signals, such as door and window open or closed status, cabin temperature, gear information and various diagnostics, help to improve the performance.

3. System Design

3.1 System Design Aspects

There are many technical issues to contend with when designing an Active Sound Management system. To list a few are LMS algorithms, number of datasets, SNR and group delay for e-mics, e-mic placement, measuring transfer functions, convergence, tracking, impulse noise rejection, wind noise mitigation over e-mics, stability versus divergence detection and mitigation, various diagnostics for speaker and e-mic polarity and performance, retry mechanisms, and more.

Tuning effort of the Active Sound Management system depends on the complexity of the requirement. Tuning is made easier by the use of a dynamometer, as it allows simulating transitions for every gear and vehicle load condition. Final check is made on a track with professional driver and NV acoustic engineer.

3.2 Acoustic Performance Range

The typical mainstream Active Sound Management systems use the traditional vehicle audio system, meaning no dedicated speakers in the headrest. This is classified as far-field systems. Under those systems, ANC cancellation is generally less than 300Hz with good performance starting to taper off above 240Hz. This is due to the limitation of the e-mic distance to the occupant head location, see **Fig. 2**. The typical ESE performance designed for high volume mainstream production vehicles do well to 800Hz and taper off at approximately a 1000Hz as localization (the ability of a listener to recognize the distance from and location of the sound source) issues become a factor. While it is possible to achieve some cancellation or enhancements with traditional low quality 15 cm speakers, some OEMs choose to use higher quality woofers or a dedicated subwoofer to achieve >25dB cancellation at 30Hz. Below 30Hz, which is 2^{nd} order frequency at 900rpm on a 4cylinder car or a 3^{rd} order frequency of a 6 cylinder car at 600rpm, the RPM signal itself is not considered accurate. Therefore, the lower bound cut off frequency is decided by the accuracy of the RPM signal and not necessarily the size of the required subwoofer.

There are other advanced ANC and ESE options including near field technology that can achieve ANC < 800Hz and ESE < 3000Hz. The software for these systems is similarly light-weight; however dedicated speakers and e-mics in non-standard locations make these systems cost prohibitive and a realm of luxury vehicles.

3.3 Audible distortion of Multimedia Content

In Active Sound Management system, distortion of music content is considered a non-issue and will not impact the audio systems tuning from the multimedia group.

ANC cancels specific frequencies by using notch filters. Properly designed notch filters with well managed energy distribution will not have a perceptible detrimental impact on the music content. ANC generally enhances the clarity of the music content since it uses RPM signal to target sounds of the multiple engine orders (harmonics) already present as background noise to the music content. ESE on the other hand either emphasizes desired engine orders (make louder) and adds many new orders that would have traditionally been created by modulating sounds using complex lengths of mechanical exhaust manifolds and baffles. ESE sounds are carefully and subtly introduced with very precise times during heavy acceleration, or high torque demand. Psychoacoustic perception is that of a powerful engine instead of music distortion.

In some fuel efficient small car applications, end users can download "fun sound-fonts" to mimic sounds of Formula-1 racing cars, etc. This model allows end user fun and residual income generation as telematics service.

Effect of ESE can be seen in **Fig. 7** which shows the high performance vehicle (350HP @440N•m). The right side chart shows the added orders to enhance the low frequencies of the sports car sound. The uneducated driver would enjoy the near 100dB muscle-car engine notes during street racing in drift mode, and would likely not notice music distortion. The educated sports car enthusiast on the other hand might be very surprised on how a 4 cylinder car sounds so amazing when there are no mechanical baffles, manifolds, and wrong number of cylinders to create such a sound signature. An OEM in the US has found Active Sound Management to be appealing and profitable.

4. Performance and Effect of the System

4.1 Analysis of ANC Measurements

Fig. 3 shows ANC production tuning made by DENSO TEN of a mid-size MY2018 North America cross-over vehicle with 4-cynder engine. The stereo system is a basic DENSO TEN system driving 4 channels, two front 6 × 9" with tweeters, and two rear 6" speakers. There are 4 e-mics in this application, one per seat. 10dB to 20dB of 2nd order and up to 10dB of 4th order noise reduction can be seen in the cruising speed RPM range in the driver seat. The performance in the remaining passenger seats is similarly good, but not shown in this article.

Fig. 4 shows ANC production tuning of a very popular mid-size SUV using the same system as **Fig. 3**. This vehicle is larger than the one in **Fig. 3**. This SUV has four main 6" speakers and 2 tweeters and also has 4 e-mics installed, one per seat. Since this is a 6 cylinder vehicle, the 3rd order engine noise is the most dominant. Although this vehicle is equipped with smaller speakers, a stable 3rd order cancellation up to 20dB can be seen in the cruising RPM range.

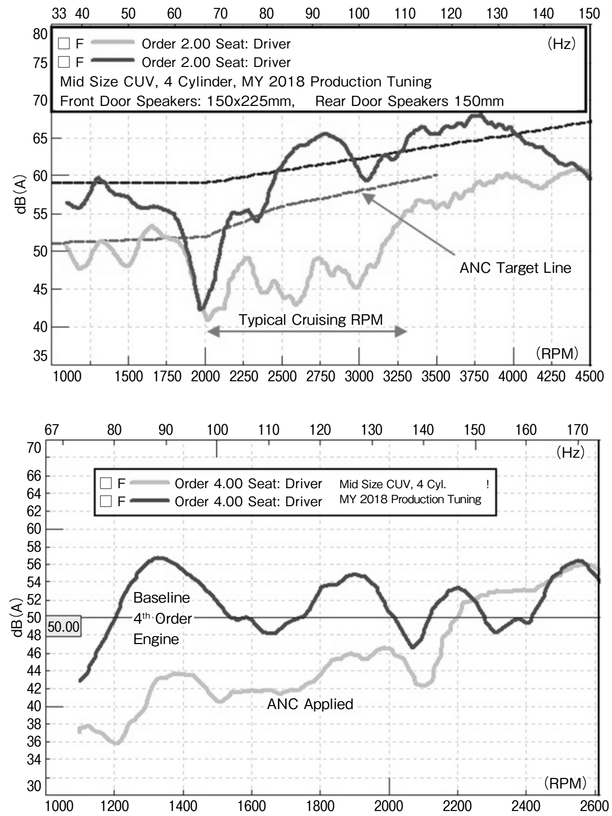

Fig. 3 ANC effect with Mid-Size CUV, 4 cyl. Engine

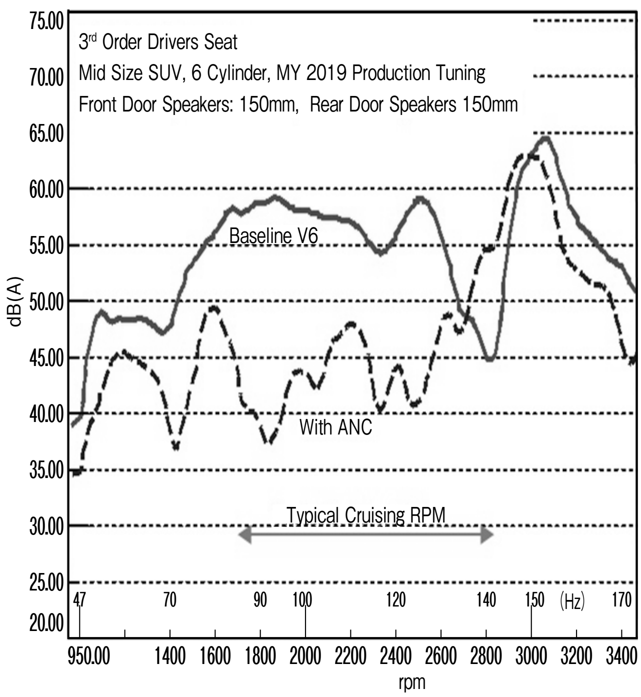

Fig. 4 ANC effect with Mid-Size SUV, V6 Engine

Fig. 5 uses Campbell Charts to show results of an ANC demonstration using the same basic radio as in **Fig. 3** and **Fig. 4**. The vehicle selected was a basic 4 cylinder minivan. This vehicle was very loud with higher RPMs and had poor speakers, thus the front speakers were upgraded to 6.5" aftermarket speakers. ANC was applied only using two front speakers and 4 e-mics for the 4 seats in the first 2 rows. The 3rd row of the minivan was not utilized for this experiment. The results shown above are for the driver seat only. Up to 10dB on 1st, up to 20dB on 2nd, and up 10dB on 4th orders cancellations were measured respectively.

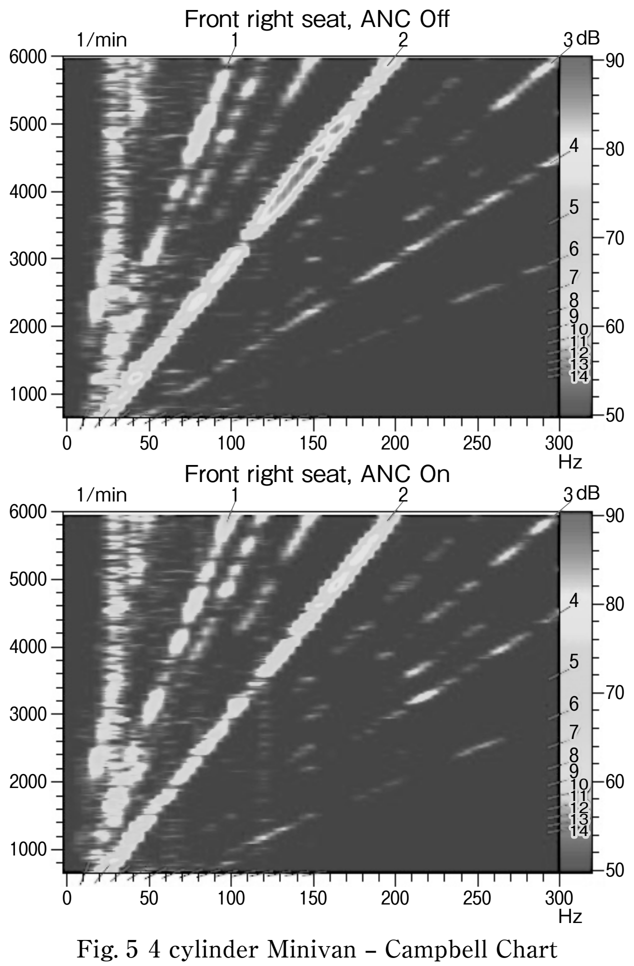

Fig. 5 4 cylinder Minivan – Campbell Chart

4.2 Analysis of ESE Measurements

The DENSO TEN demonstration vehicle, **Fig.6.**, was used to show different kinds of European sports car sounds with and without the aid of a subwoofer with up to 10 orders of enhancement to 600Hz. The lower-left chart in **Fig. 6** shows the status before tuning; the upper-right is the result of enhancement on low frequency by sub woofers; and the lower-right is the result of enhancement on higher frequency. The zones surrounded by red-colored dotted line are enhanced, which represents the effect of ESE. **Fig. 7** is an actual 4 cylinder turbo sports car with 350HP@440nm torque. This was measured for benchmark by DENSO TEN. As the effect of emphasis can be seen in the Campbell Chart, this vehicle has ~21 orders of enhancement with loud 100dB sound levels that might finally sound like a 5 cylinder engine.

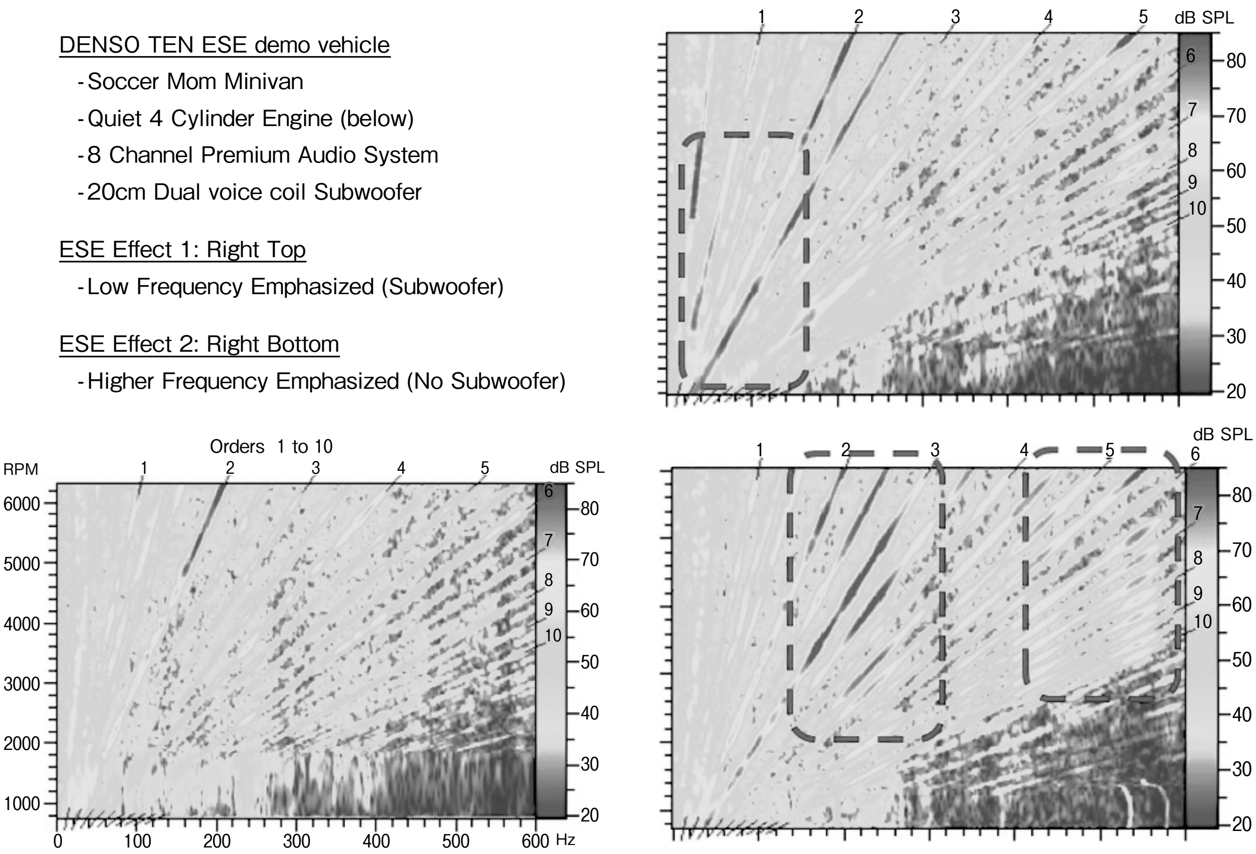

Fig. 6 ESE Effect using Campbell charts (Normal, w/ Sub woofers, w/high-frequency enhancement)

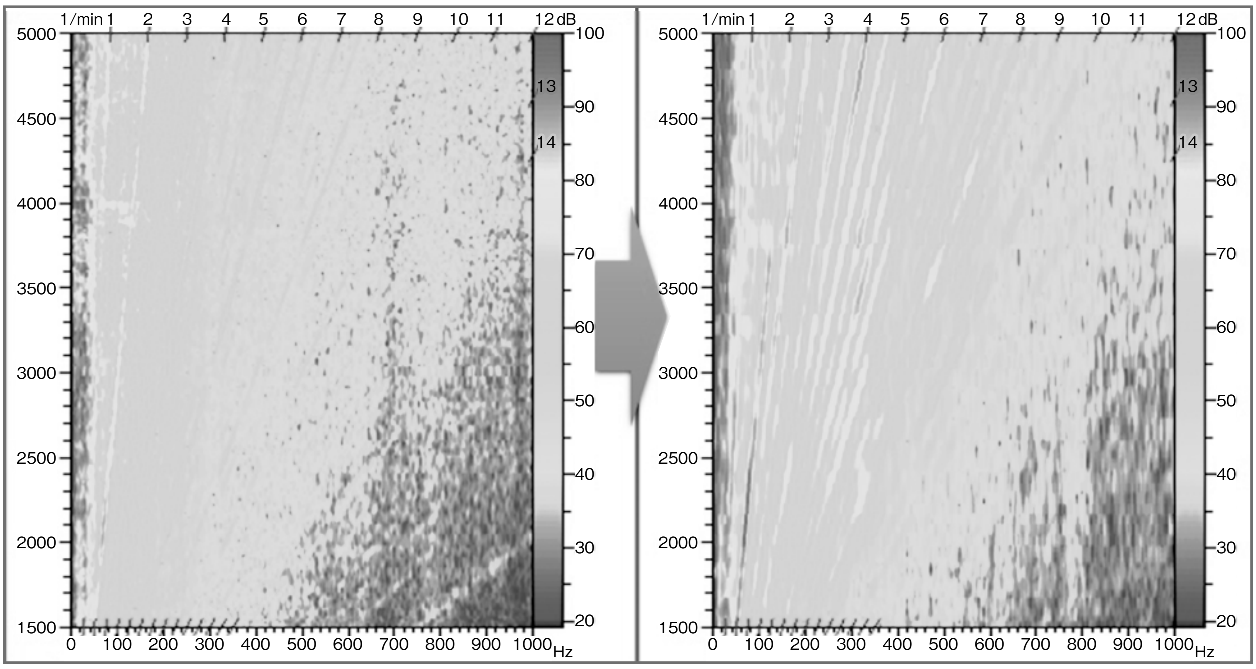

Fig. 7 ESE Effect in 4 cyl. Turbo 350HP North America Production Sports Car (3rd Gear shown)

5. Conclusion

Active Sound Management technology has been in automotive luxury segment for a decade and those drivers have enjoyed the benefits of luxury and excitement. Recently it has been applied to Mid to Low grade vehicles. Active Sound Management application is expected to be enhanced since it also has a potential to be telematics service contents that improve acoustics environment by Over The Air (OTA) or USB download. Active Sound Management is also considered as a solution for wind and road noise cancellation. We would like to continuously develop this technology for future.

References:

Fig. 1 – Rolf Schirmacher of Müller-BBM Active Sound Technology GmbH," Active Noise Control for the 4.0 TFSI with Cylinder" in SAE International, 2012-01-1533,2012,

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