Executive summary
Improving in-cabin comfort for vehicle occupants has been gaining more attention recently. As automakers strive to offer new features while keeping vehicle weight low, active methods of noise reduction play a vital part in reducing noise, vibration and harshness (NVH), thereby improving the in-cabin experience. The availability of powerful processors and sensors at an affordable cost, software algorithms, modern tuning techniques for sensor placement and the market trend toward rapid integration of these components has accelerated the commercial adoption of active noise cancellation (ANC) technology. Mentor, a Siemens business, offers a suite of innovative automotive audio solutions aimed at minimizing cabin noise generated by the engine and road.
Introduction
This white paper explores how the ANC technology can help conventional and all-electric automakers. It discusses the end-to-end process of implementing a robust active noise canceling technology to reduce unwanted noise sources and improve the driver experience, as well as how this can be adopted and implemented in the vehicle. In a related white paper entitled, “Leveraging active sound design for automotive,” we explain new solutions to enhance vehicle sound, focusing on active sound design (ASD) and describing the engineering process for adding meaningful sounds that meet both brand and engineering targets.

The global automotive space is in a disruptive phase. Automakers are looking at products and technologies that can set them apart in the marketplace by offering consumers unique value propositions. Governments around the world have mandated stricter fuel efficiency standards. They are constantly pushing automakers to increase vehicle mileage and reduce emissions. Due to this, automakers are already sensitive to the weight of the vehicle as it directly impacts fuel economy. Even with the recent rise in popularity of all-electric vehicles, a lower vehicle weight would directly translate to a larger range. These trends benefit automakers making the shift from a hardware-centric passive noise cancellation approach to a software-enabled active noise cancellation solution.

Conventional vehicles generate an ample amount of noise with the internal combustion engine (ICE) being a significant contributor. It is comparatively easier to cancel this noise as it is periodic and predictable. Solutions already exist to cancel out the noise from the internal combustion engine. Tackling the other sources of noise is a more challenging problem as they are aperiodic and can occur at any time; for example, wind or road noise. These noise sources equally affect all types of vehicles. The ANC solution aims to improve the overall in-cabin experience for all occupants. With the rising adoption of autonomous vehicles, where a driver may be doing tasks other than driving, it is even more likely the removal of background noise from the vehicle cabin using ANC technology will only increase its importance.

Active noise control
The move toward electrified vehicles increases the need to control all noise sources, which has its costs and limits. ASD can be an important element to further enhance the driver’s experience and reintroduce some of the masking effect that was lost when the internal combustion engine was replaced.

It may be preferred to add sound to the vehicle. However, there are many situations where the sound of silence may be preferred. That is even more so with the increasing trend towards autonomous vehicles. There is one more important technology that is available: implementing an active noise canceling (ANC) system.

Current state of vehicle audio and infotainment
The J.D. Power market research company conducts an annual survey of U.S. vehicle owners that addresses top complaints. The findings of the survey offer a window into where the gaps between expectations and performance exist.

In its 2021 survey they found that, “[compared to the previous year] the Audio Communication Entertainment Navigation shows marginal improvement and remains the category with the most problems reported.”

Clearly, customers are expecting more from this category. It seems apparent that legacy approaches to address many of these issues have come up short. For example, traditional methods of adding more passive dampening materials to minimize external wind/road noise and make the interior cabin quieter can only do so much. Moreover, in addition to elevating costs, passive dampening adds incremental weight, which has a negative effect on the fuel economy of the vehicle. Carmakers are turning to technology, especially intelligent software-driven solutions, to tackle these problems. Let’s look at the example of noise cancellation and how active, software-based methods offer an answer.
Transporting audio within the car

Although acoustics has long been a key automotive design consideration, interestingly enough most improvements to the in-cabin experience have centered on the overall in-vehicle infotainment (IVI) application. According to conventional wisdom, whatever worked for a better IVI experience was also deemed good enough for audio. This made sense since audio and video usually went hand-in-hand.

However, the emergence of acoustic-centric applications such as ANC, engine sound enhancement (ESE) using active sound design, acoustic vehicle alerting system (AVAS) and other technologies have led designers to take a much closer look at audio technology on its own.

But first things first: A fundamental component that enables these new audio applications is the underlying bus technology. The availability of an advanced bus infrastructure for the efficient transportation of audio data makes the shift from passive to software-based approaches much easier and lower cost. The Automotive Audio Bus (A²B) developed by Analog Devices promises to be an innovative technology dedicated to transport audio.

A²B: digital audio over lightweight cable

A²B gives carmakers a cost-effective way to deliver multi-channel digital audio, control data and power all over the same lightweight unshielded twisted pair (UTP) cable. Cable and assembly costs for A²B systems can be up to 75 times lower than analog alternatives, and the lighter weight can also enable lower carbon dioxide (CO₂) emissions. A²B also includes system-level diagnostics and compliance with automotive electromagnetic compatibility (EMC), electromagnetic interference (EMI) and electrostatic discharge (ESD) standards. And with deterministic, low-latency performance (50 µs) and 50 megabit/second (Mbps) bandwidth, A²B is well suited for high-quality audio and other applications, including infotainment and noise cancellation.

A²B-based connectivity delivers many benefits, especially relative to traditional analog-based networking still in use in the vast majority of vehicles on the road. Thanks to phantom power and a single master/multiple slave line topology that supports daisy chaining of nodes, A²B systems eliminate the need for local component power supplies and control processors to manage software overhead. As a result, A²B provides an easy and efficient way to link a head unit to an array of speakers and amplifiers around the vehicle in a scalable daisy chain, which is vastly simpler than implementing a high-end sound system with many independent, point-to-point connections.

As is always the case, the popularity of an emerging technology is dependent on, and can also be measured by, the reception of early adopters and other ecosystem players. There are several examples of A²B industry adoption and ecosystem growth, most notably Ford’s January 2016 announcement that it will use A²B as its primary infotainment network technology. Since then many original equipment manufacturers (OEMs) and automotive parts suppliers have announced adoption of the A²B technology for their infotainment network. A²B can be used for all in-car audio communication and noise cancellation. From an ecosystem perspective, the Mentor Automotive Business Unit is among the first independent tool vendors providing critical A²B test support, including the A²B Analyzer System – a third-party development platform engineered to help significantly reduce development time for such systems by speeding configuration and functional testing.

Leveraging active noise cancellation

Unlike passive noise cancellation, which uses physical noise dampening materials, active noise cancellation is implemented using digital signal processor (DSP) techniques. The idea behind active noise cancellation is quite simple – carefully placed microphones pick up noise, which is then processed and a 180-degree out-of-phase anti-noise signal is generated to cancel the undesirable noise. Active noise cancellation is already available in some car models, though it has generally targeted periodic, low-frequency engine noise. Although every engine is unique, the noise behavior is predictable and typically dependent on the engine’s rotation speed. As a result, engine noise can be modeled to a fair degree of certainty and then subsequently dealt with.

But engine noise is only a part of the overall picture. The second, trickier source of noise comes from the road – broadband in nature, unpredictable and almost impossible to model. Unlike engine noise, road noise also varies with changes in the road surface. Most noise-cancellation solutions available today only deal with engine noise and are incapable of handling road noise. The issue of tackling road noise has gained even more importance with the emergence of electric vehicles (EVs), which feature electric motors instead of gasoline engines. Although EVs produce no engine noise, road and wind noise must still be addressed.
Although the premise of canceling road noise is fundamentally the same as canceling engine noise, the complexity of the challenge requires additional components to reliably track and stop noise on a real-time basis. A combination of carefully placed accelerometers, microphones and speakers work in conjunction to pick up road vibrations, process the resulting sounds and then generate the required anti-noise directed at the car’s occupants. Proprietary, high-performance algorithms ensure fast convergence, resulting in rapid adaptation and responses to noise from changing road surfaces.

An even bigger challenge is how to deploy a cost-effective combination of microphones, accelerometers, hardware and software to cancel the random broadband road noise. Until now, technical and cost challenges have prevented carmakers from offering broadband noise cancellation. However, the combination of A²B networking technology, powerful DSPs, off-the-shelf A²B-based components (accelerometers, microphones) and software intellectual property (IP) are bringing the road noise cancellation solution significantly closer to reality. By offering deterministic latency, A²B is perfect for networking microphones, accelerometers, and other components.

Advanced active noise cancellation technologies such as the Mentor broadband ANC solution have been designed to precisely tackle the dual problem of canceling engine noise and road noise. Using ANC as an example, an advanced algorithm effectively cancels both engine and road noise to improve the environment within the car cabin. Quiet zones created around the driver and passengers cover steady state, dynamic and nonperiodic components of engine, transmission and road noise without interfering with the enjoyment of music, the utility of audio-based navigation systems or the sirens of emergency vehicles. High-performance solutions such as ANC enable advanced functionality with minimal hardware components.

Somewhat paradoxically, other emerging audio applications involve sound enhancement for both driver enjoyment and safety. The controlled rumble of a high-end sports car engine, for example, is a big part of a car’s signature appeal, which is why that engine noise can be digitally enhanced and piped into the cabin. Other sound-generation applications include various acoustic alerts, from chimes that play when the car is started or when parking as well as other safety alerts that combine to form the car’s personality, brand identity and thus its relationship to drivers and passengers. It goes without saying it is desirable, or even a requirement, for these multiple audio applications to coexist in the same vehicle. Without an innovative software-based solution, this would not be possible.

**ANC system from design to deployment**

The availability of powerful processors and sensors at an affordable cost, software algorithms, modern tuning techniques for sensor placement and the market trend toward rapid integration of these vehicle components has accelerated the commercial adoption of ANC technology. As automakers strive to offer new features while keeping the vehicle weight low, active methods play a vital role in reducing NVH and thereby improving in-cabin experience.

Table 1 shows key aspects of ANC algorithm that automakers need to consider and emphasize while adding noise management features in the car.

#### Key features of an ANC algorithm

| Broadband capability addressing engine and road noise | Faster convergence that handles rapidly changing road noise conditions |
| Easily customizable to fit cabin geometry | Real-time telemetry reporting |
| Multiple in-vehicle “quiet” zones | All digital |
| Availability of tools to support tuning | Low MIPS/CPU overhead and portable |

Table 1: Key features of an ANC algorithm.
The process
The ANC system adoption process can be broken down by any OEM into three main steps: design, validation and deployment.

The design of the ANC algorithm is a creative process and takes several years to perfect. Hyundai Motor Group went through six years of research and development (R&D) for the mass production of road active noise control (RANC). OEMs can significantly cut down on ANC algorithm design and development time by using an off-the-shelf solution like the Mentor ANC solution.

The tuning and validation phase is kicked off by selecting the optimal accelerometer and microphone locations based on available mounting positions in the vehicle. Simcenter™ software, which is part of the Xcelerator™ portfolio, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software, helps engineers acquire sensor data and calculate optimal sensor positions for ANC. In a typical passenger vehicle system, four to six three-axis accelerometers are installed under the body, on the passive side of the suspension near body mounts and shock/strut mounts, and four to six microphones are installed in the headliner.

An accelerometer placement study is conducted to determine the number of accelerometers, best locations and which axes to use to meet the desired ANC performance, and a microphone placement study is conducted to determine the number and best locations to meet the desired performance while avoiding restricted areas such as sun/moon roof locations.

Accelerometers are used to measure the source in a road noise cancellation (RNC) system and provide reference signals for the ANC algorithms. The accelerometers are used to collect vibration data and send it back to the DSP for processing. After mounting the accelerometers and microphones at potential locations, data can be collected by having the vehicle run over multiple surfaces and observe the measurement logs. Analyzing the collected data and the coherent in-cabin noise data, we can narrow down the best locations for the placement of the accelerometers.

In a typical far-field passenger vehicle system, four to six speakers are used for ANC output. Although some premium audio systems may have many more channels, there is a trade-off to be considered to balance DSP requirements and number of outputs. In a far-field ANC
A near-field system requires speakers closer to each vehicle occupant’s ears (for example, head rests or seat shoulders). It is important that speakers have good low-frequency response in the desired band of cancellation (for example, 30 to 500 hertz). A subwoofer is helpful, but not necessarily required, depending upon performance requirements. Next, perform the tuning process, which includes selecting the parameters that maximize cancellation and prevent boosting. The Mentor ANC has several algorithms that are designed to limit the adaptive filter’s ability to amplify undesired signals. These are exposed as tuning parameters and prevent the algorithm from runaway situations. The more aggressive the stability of control settings, the less effective the noise cancellation will be. So, balancing performance and stability is an important part of tuning.

Some tuning parameters can be adjusted by evaluating performance at each ear position, making minor adjustments to enhance ear position cancellation as needed. This has to be followed up by stability tests that validate the changes in tuning parameters do not cause the algorithm to diverge.

If the tuning and validation steps were not performed with the target hardware on which the final deployment is to be made, port the ANC algorithm and the selected tuning parameters to the DSP of the OEM’s choice and revalidate if everything is working as expected. In case of poor performance, conduct the tuning process again until the algorithm is at least stable and working effectively.

ANC solution suppliers like Siemens also work with the OEMs in the tuning, validation and deployment process so the entire process, from design to deployment, provides the best results.

Figure 2. Steps involving ANC system design to deployment process.
Conclusion
Active noise cancellation technology helps manufacturers create in-cabin quiet zones using software that significantly improves the driving experience and their brand image. Manufacturers also benefit from reduced dependence on passive techniques for noise cancellation and using the all-digital automotive audio bus.

With the availability of software-based noise cancellation and enhancement solutions, engineers have one more tool in their arsenal to tackle noise-related problems. But as referenced, automotive audio system design has until recently been the domain of engineers focused on information and head unit systems, while the challenges of reducing extraneous noise and vibration in a car are traditionally handled by an OEM’s noise, vibration, and harshness team. Therefore, to gain maximum advantage from the move toward software-based acoustics solutions, carmakers and their suppliers will need to work across traditional organizational boundaries to unleash the promise of software-enabled audio. As these software-enabled solutions start to consistently roll out in production vehicles, one can expect to see better customer satisfaction scores in surveys.

The automobile of the future is changing in profound ways, so it makes sense that audio is finally emerging from the shadows to take its rightful place as both a key enabler of new ideas as well as a differentiator for carmakers.

References
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