



A Software-Based Approach to Active Noise Control in Automobiles

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Everyone wants a car that consumes less fuel. In fact, some studies indicate that car buyers now rank fuel economy as the top factor in choosing a new vehicle. To address this demand, as well as laws regulating fuel efficiency and carbon emissions, automakers have devised a variety of measures. These include variable cylinder management (i.e. deactivating cylinders under conditions of light engine load), operating the engine at lower RPM, and cutting back on passive damping materials to decrease vehicle weight.

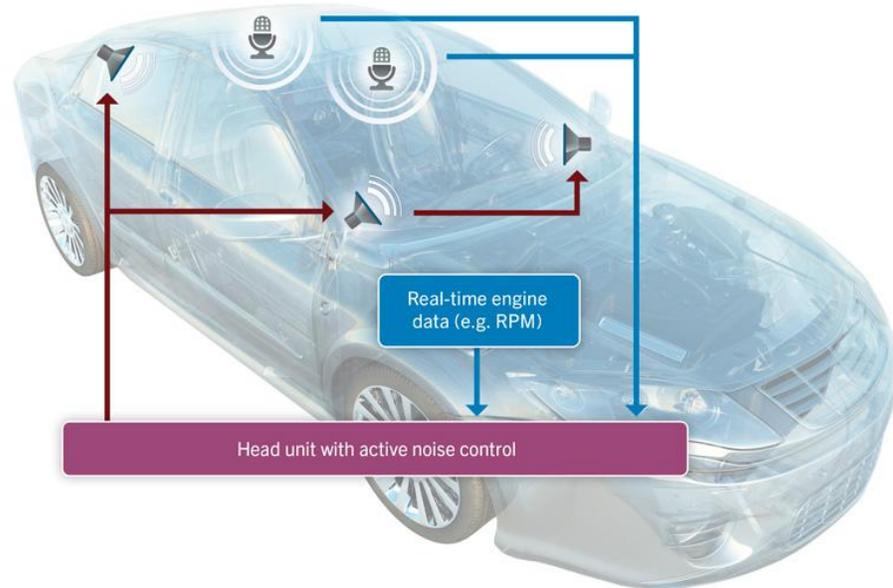
The good news is that these measures help improve fuel economy; the bad news is that they often result in objectionable in-vehicle noise. This “boom” noise originates from the engine and induces loud, low-frequency tones (under 150 Hz) inside the cabin that can cause driver fatigue. The noise is proportional to engine speed and is often caused by increased vibrational energy from the engine or drive-train that is transferred into acoustic energy inside the cabin. It occurs during normal acceleration and deceleration, and at cruising speeds when cylinders are deactivated. The reduction of passive noise control materials only exacerbates the problem. To counteract this noise, automakers are employing active noise control (ANC) technology — a very effective approach to reducing in-cabin engine noise that can function without any awareness on the part of the vehicle occupants.

Elementary... in principle

To cancel unwanted engine noise where the driver or passengers are sitting, an ANC system emits synthesized “anti-noise” of equal amplitude but opposite phase through the car speakers. To perform effectively, the system needs real-time engine operating data, specifically RPM data; it also needs input from one or more microphones placed as close as possible to the heads of the driver and passengers. The real-time engine data helps determine the frequencies to be reduced, while the microphones allow the system to continuously monitor noise levels in the cabin and therefore adapt to changes in acoustic conditions.

While ANC may seem elementary in principle, achieving optimal performance is anything but. To begin with, every vehicle interior has unique acoustic characteristics that are affected by the location of seats, the materials used in the cabin, and the position, number, and type of speakers and microphones. Because all of these factors influence how the ANC system performs, the system must be calibrated and tuned separately for every vehicle model. The system must also adapt quickly to dynamic changes in cabin acoustics that result, for example, from changes in seat positions and from windows opening and closing. Moreover, the system must be robust — it cannot become

unstable or degrade the audio quality inside the cabin should, for instance, a microphone stop working.



ANC systems use real-time engine data and sampled microphone data to construct “anti-noise” that is played over the vehicle speakers to reduce engine noise where occupants are sitting.

Considerations and tradeoffs

Most commercial ANC systems use a dedicated hardware module. Automakers are beginning to realize, however, that it's more cost effective to run software-based ANC on existing silicon, either in the head unit or in the power amplifier of the audio system. The DSPs and application processors in today's infotainment systems can accommodate a wide range of tasks, including ANC. When ANC is integrated into the infotainment system, the various audio processing functions, including ANC and hands-free acoustic processing, can easily cooperate with one another and share information. In an integrated system, a host application, typically running on the head unit or amplifier, can remain in full control of the audio processing chain and can invoke the ANC software library to perform ANC on an as-needed basis.

Noise vibration and harshness (NVH) engineers have the task of characterizing and optimizing sound quality in a vehicle. Choosing the number of microphones and speakers in a system is a trade-off between cost, performance, and computational resources, and often depends on vehicle size. Thus, an ANC solution should provide implementation choices. These include the ability to run on a variety of processors or DSPs (with or without an OS) and the flexibility to accommodate almost any arrangement of inputs and outputs — from a one-microphone, two-speaker configuration to a six-microphone, six-speaker setup.

To ensure optimal selection and placement of microphones and speakers, the NVH designer needs to consider several factors:

- The frequency response of microphones and speakers must be relatively flat, and cannot roll off within the targeted frequency range. The low-frequency response of the speakers determines the lowest frequency at which the ANC system can reduce engine noise.
- Production variance of microphones and speakers must be reasonably consistent to ensure that the system behaves identically in all vehicles of the same model.
- Speakers must produce output of sufficient acoustic power to cancel engine noise at listening positions. Audio playback (not ANC) usually dictates the maximum acoustic power output requirements.
- Speakers cannot produce perceivable non-linear distortion when driven by ANC; otherwise, they will reduce the benefit delivered by the ANC system.
- Microphone signals should not clip under high noise conditions.
- Microphones should be omnidirectional and be placed as close as possible to each listening position.

In general, microphones designed for hands-free voice communication cannot also be used for active noise control because the performance requirements for the two functions differ.

How does a software-based ANC solution measure up?

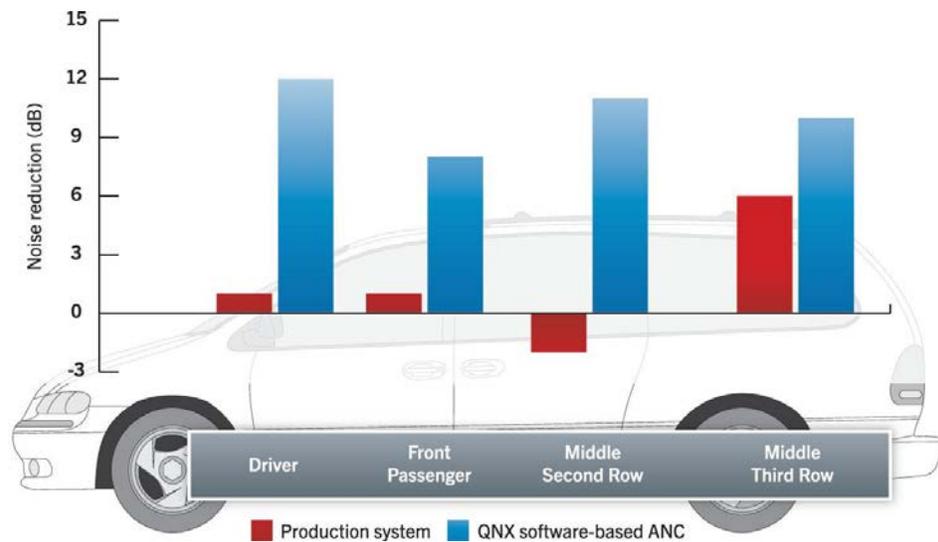
To answer this question, we conducted tests to compare noise reduction performance of the ANC software library from QNX Software Systems to that of an ANC system deployed in a popular 2012 minivan. The minivan, which is equipped with a V6 engine, uses cylinder deactivation to improve fuel consumption and has a dedicated, self-contained ANC module. The module uses two microphones, one near the rearview mirror and the other in the center ceiling above the third row. It also uses up to four loudspeakers in the left and right front doors and sliding doors, and one subwoofer in the trunk.

Direct access to all of the existing microphones and speakers wasn't feasible for the purposes of these tests, so comparable microphones and speakers were placed as close as possible to the existing ones. One exception is the front microphone, which was placed closer to the driver's head. Only three speakers were used for the software-based setup: left and right front-door speakers and the subwoofer.

Data was collected under multiple conditions, including a variety of cruising speeds on smooth quiet roadways, gradual and rapid acceleration to 50 mph, and throttling the engine with the vehicle in idle. As anticipated in a vehicle with cylinder deactivation, ANC had the greatest effect at cruising speeds when the vehicle shuts down half of its cylinders to save fuel. Although both ANC systems can target more than one frequency concurrently, test results showed the main perceptual effect occurred with the reduction of the vehicle's predominant engine tone. The frequencies of this tone at the various measured speeds were roughly 38 Hz (35 mph), 35 Hz (45 mph), 43 Hz (55 mph), and 50 Hz (65 mph).

Compared to the production system, the software ANC system showed equal or better noise reduction for cruising speeds ranging from 35 mph to 65 mph. At these speeds, the production system achieved an average noise attenuation of 6 dB at the driver’s position, while the software ANC solution achieved 11 dB. At a steady state speed of 65 mph, the production system achieved a 1 dB improvement with ANC activated, while the software ANC system achieved a 12 dB improvement. Figure 2 illustrates the subset of the noise attenuation results at a cruising speed of 65 mph. Higher bars indicate better attenuation.

Some vehicles also use an active control engine mount (ACM) system to reduce engine vibration. While an ANC system can work in tandem with ACM to cancel noise that results from cylinder deactivation, the results reported here are direct comparisons of ANC technologies.



Noise reduction measured at a cruising speed of 65 mph shows how a software ANC solution can achieve up to 12 dB of noise reduction of the predominant engine tone, outperforming a production system at all measured locations.

Enhancing the user experience

Consumer perception of overall vehicle quality hinges on interior sound quality. This perception includes the quality of hands-free calls and music playback, as well as an interior absent of engine and road noise. Automakers are starting to introduce sound management technologies into different areas in the car, not only to remove unwanted sound, but also to inject desirable sounds into the car interior. For instance, engine sound enhancement technology allows automakers to create customized sound that is synchronized to engine speed and emitted through the vehicle’s loudspeakers. Generated sound can also be piped externally to alert pedestrians of an approaching vehicle — especially beneficial with electric vehicles, which can be nearly silent. These new technologies will enhance the user experience, but uptake will depend on cost and on ease of integration within existing acoustic systems.

For more information on QNX ANC technology, visit www.qnx.com or send email to anc@qnx.com.

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