Abstract
Noise cancellation has become more than just a luxury in automotive. Health-focused consumers now demand products that prioritize occupant safety and wellbeing. The adverse health effects of noise on drivers and passengers have long been recognized. Removing unwanted sound and creating a more pleasant acoustic environment will become a point of brand differentiation – and eventually a legislative requirement. These new Active Acoustics innovations support all megatrends from electric to autonomous, connected and shared driving.
Active acoustics technologies continuously create appropriate destructive acoustic fields to reduce unwanted engine, road, HVAC and wind noise in passenger compartments. This is usually done by leveraging the loudspeakers of the existing audio system and by placing a set of sensors on the chassis and inside the headliner or the seats. The Active Road Noise Cancellation technology can lower unwanted noise peaks by 10dB and overall noise levels by 3-4dB – the equivalent of reducing the volume of the car’s sound system by four levels. The Quiet Bubble™ technology can create an almost physical space around 1ft in diameter around each occupant’s head, which allows the driver or passengers to experience a quieter environment in their seat specifically. In the next generation, this will be expanded into the “Personal Sound Bubble™” technology, where passengers can listen to their own music without it overlapping with other occupants’. For example, the driver can be listening to navigation instructions while the passenger listens to their own music or a podcast.
Given the diversity of vehicle variants and the sensitivity of the performance of active acoustics to the locations and types of sensors and speakers used, computer aided design (CAD) tools play an important role in vehicle development. Instead of a tedious trial and error optimization process, a CAD tool can perform automated evaluations to achieve several optimal configurations. The Active Acoustics simulation tools replace in-vehicle lengthy and costly measurements and evaluate the acoustical energy level at targeted points in the vehicle.
In this work, Silentium’s Acustifusion™, a CAD & cloud tool to support integration of active acoustics solutions into vehicles is discussed. The objectives are to provide automotive designers with:

1. Rich libraries of sensors and loudspeakers.
2. Design flexibility to optimize the number and the locations of the sensors.
3. Detailed studies of acoustic performance in terms of acoustic parameters.
4. Quantitative evaluation of the acoustic comfort.
5. Evaluation of the acoustic performance and comfort under diverse environmental conditions.
6. Integrity check routines to support diagnostics for development phases, end of line (EOL) production phase, and dealer support.
7. Employing an NVH-focused CAD system upfront, development teams can test and enhance acoustic performance at all stages of the design process.

Introduction
The evolution and development of modern sound technology have created new benchmarks within the automotive industry for both the OEM and consumer. Silentium’s aggregations of core ANC technology with tuning and prediction tools in the development of the Quiet Bubble™, the innovative Personal Sound Bubble™, and Silentium's CAD SW AcustiFusion™, all of which enables CASE automotive market trends, have positioned Silentium for new innovative technology resulting in superior automotive sound solutions.

Active Noise Cancellation
Active noise (ANC) reduces unwanted sound by utilizing opposite sound waves that collide and eliminate or “cancel” each other. This technology provides several advantages over traditional passive soundproof insulation by reducing the use of thick and heavy materials for less pollution, simplifying installation, maintenance, and replacement, and increasing noise cancellation efficiency.

Silentium's Active Road Noise Cancellation (ARNC)
Silentium ARNC solution utilizes strategically positioned sensors installed in the chassis and inside the headliner or seats and leverages the existing audio system's loudspeakers. The sensors monitor unwanted road noise and signal the onboard software control unit installed with Silentium software, which plays an equivalent anti-noise signal through the vehicle's
speaker system. Thus, the pressure waves from both the unwanted exterior noise and manufactured anti-noise reach occupants' eardrums at precisely the same time and cancel each other out.

Today, Silentium's Active Acoustics cancels up to 90% of unwanted road noise across a wide band of frequencies – from 20Hz to 1kHz, offering a no-compromise, win-win solution to balancing vehicle weight and driving dynamics resulting in a superior acoustic driving experience.

**Silentium's Active Acoustics Solution and the OEM**

Active Acoustics technology is a credible alternative to costly passive noise reduction systems, such as insulation foam and asphalt damping, which add considerable weight to the vehicle. The drawbacks of passive noise reduction systems push car manufacturers to find new ways to improve in-car acoustics. For example, saving weight is essential to help extend battery life in Electric Vehicles (EV'S) and extend the driving range. Additionally, with the removal of engine noise in EV's other sounds are accentuated; OEMs look to Active Acoustics to offer their customers a quieter ride without the drawbacks of heavy materials.

Recently, vehicles' noise, vibration, and harshness (NVH) characteristics have attracted significant attention from vehicle manufacturers. As a result, reducing the interior noise of a car to improve driver and passenger comfort and safety has become a point of brand differentiation. Noise cancellation is more than just a luxury in the automotive industry today. Silentium's innovative solutions meet the needs of health-focused consumers that now demand products that prioritize occupant safety and well-being. The adverse health effects of noise on drivers and the dangers of driver distractions through unwanted noise have long been recognized. Removing unwanted noise and thereby minimizing driver distraction can ensure driver safety by enabling the vehicle's safety dashboard and notifications sound to be heard as well as creating a more pleasant acoustic environment.

**Quiet Bubble™ – Patented Active Acoustics That Raises the Bar**

The Quiet Bubble™ is a spatial Active Noise Reduction solution fueled by the patented Active Acoustics technology that introduces a personal quiet zone around the driver's and passenger's head. Silentium's QB™ technology proved efficient in noise reduction by leveraging the OEM's existing infotainment and audio systems with the installed sensors in the cabin that send data signals to the onboard software control unit installed with Silentium's software. The Quiet Bubble™ technology creates an almost physical space 1ft in diameter around each occupant's head. The Active Acoustics produce a continuous destructive acoustic
field that emits the anti-noise signals through the vehicle’s speaker system. Silentium’s Quiet Bubble™ solved the noise and vibration challenges, enhancing the user experience for voice and sound management, allowing the driver or passengers to experience a quieter environment in their seat specifically.

The Personal Sound Bubble™ Drives the Future
The Quiet Bubble™ technology allows the driver or passengers to experience a quieter environment in their specific seat by creating an almost physical around the headspace, whereas the "Personal Sound Bubble™" technology innovates this tech further – in the next generation, like using headphones in a vehicle, but without the headphones. Silentium’s Personal Sound Bubble™ affords multi-zone sound control where passengers listen to their music without overlapping with other occupants. For example, the driver can be listening to navigation instructions while the passenger listens to their music or a podcast. The PSB™ technology is an advanced signal processing method for superior control of the sound waves by audio phase control-beaming. Furthermore, Silentium’s PSB™ tech provides customization and design with end-to-end sound control design for the OEM, modifying driving assisting systems, or customizing the personal & safety audio portions in manufacturing. Whether you’re a business person who needs to teleconference or take a private call, at the same time other occupants listen to public radio, or a parent who needs to hear navigation systems acutely while the children listen to their favorite music group – all occupants can design their PSB™ according to individual needs. The advantages of the Personal Sound Bubble™ are extant as it includes several integrations that affect the driver, from safety to personal enjoyment to health and well-being for every occupant in the vehicle. The Personal Sound Bubble™ provides localized audio/video information and warning sounds, enabling driving-assisted features and personalized navigation and entertainment through the system that does not prohibit the emergency audio signals and sounds necessary for safe navigation of the vehicle.

Silentium’s AcustiFusion™ – The Ultimate Acoustic Tuning & Prediction Tool
Given the diversity of vehicle variants and the sensitivity of the performance of active acoustics to the locations and types of sensors and speakers used, Computer-Aided Design (CAD) tools play an essential role during vehicle development cycles. A CAD tool can perform automated evaluations to achieve optimal configurations instead of a tedious trial and error optimization. The Silentium developed CAD tool AcustiFusion™ is a high-tech tuning & calibration software tool kit with a PC and mobile-based Graphic User Interface (GUI) SW for the ANC, and PSB™
features automotive engineers utilize. AcustiFusion™ simulation tools replace lengthy and costly in-vehicle measurements and evaluate the vehicle's acoustic energy level at targeted points. In addition, it provides active acoustics: simulations, performance prediction, design, and tuning platform, which simplifies the integration of Active Acoustic solutions into the customers' products.

The central AcustiFusion™ features consist of signals analysis, transfer function estimation, design parameters calculation, performance prediction through simulation, real-time vehicle data indications, and system components validation.

AcustiFusion™ is beneficial during all development and production phases and basically through the product's complete life cycle. It is an easy-to-use software that contributes to the engineering teams by shortening the overall development time. During the pre-production stage, or proof of concept activity, AcustiFusion™ performs sanity checks, system set-up QC, noise mapping activities, tuning, and performance, as well as robustness validations.

AcustiFusion™ follows the same phases from mule development to production vehicles during production-intent programs, including final components functionality and installation checks. After production, AcustiFusion™ analyzes maintenance activities, for example, troubleshooting, debugging, and support purposes. In addition, AcustiFusion™ is an automated Tuning Tool that helps OEM/Tier 1 engineering teams collaborate with Silentium R&D engineers to create the perfect interior space regarding active noise and sounds. Furthermore, AcustiFusion™ helps create better optimized and more robust production calibrations for the customers at their convenience. The Covid19 period illustrated this advantage, with minimum need for extended, on-site supplier presence and limiting potential disruption at the customer's facilities.

AcustiFusion™ goes hand in hand with Silentium strategic growth plans with a customer-focused approach and regulatory requirements. Specifically, it is intended to provide a "one-stop-shop" for current and future Active Acoustic solutions. In addition, this All-in-One Tuning tool will surely simplify customer's integration of different activities and reduce end-to-end production costs.

**Silentium's Holistic Solutions and CASE**

In addition to answering the complexity of NVH in sound control, Silentium's innovative solutions play an important role in all the automotive mega trends - Connected, Autonomous, Sharing, and Electric – known as CASE.

Connected vehicles: An essential requirement of most connectivity applications in vehicles (phone calls, in-car communication, navigation, etc.) is the ability to deliver clean and localized...
voice. Any noise, whether external noise intrusions like road noise or an unwanted sound like music played somewhere in the vehicle, reduces the quality of communication and the ability to use the desired voice-activated application. With its Quiet Bubble™ (QB™) Active Noise Cancellation and the next generation Personal Sound Bubble™ (PSB™) sound zones technology & solutions, Silentium creates quiet and separated acoustic environments enabling reliable and superior voice-enabled connectivity.

**Autonomous vehicles:** While the final goal of fully autonomous vehicles is still some years away, vehicles with partially autonomous level capability, such as levels two and three, are starting to appear in the market. One of the significant issues with those levels is re-engaging the driver in undefined emergencies and asking them to control the vehicle, including situation awareness and the alerting process. Acoustic cues play a crucial role in alerting the driver even if they are not looking in the right direction and can provide an immediate intuitive understanding of the environment. Silentium's acoustic solutions answer these crucial needs and localize the warning sounds around the driver without disturbing other vehicle occupants. Dashboard signaling systems are easier to hear.

**Shared vehicles:** Any shared vehicle must allow its users to personalize and create private acoustic environments. Without the possibility of listening to one's favorite music (and not disturbing other users), receiving private phone calls, or just relaxing with minimal disturbance from outside noise, Silentium's Personal Sound Bubble™ (PSB™) is the ideal sound zone solution to this challenge.

**Electric vehicles:** With the elimination of the internal combustion engine (ICE) in electric vehicles (EVs), one of the significant noise sources in the vehicle disappears. However, this also removes the masking effect of the ICE on other noises such as road, wind, or air-conditioning, thus making these noises much more noticeable to EV users. Hence, the demand for Sound management, specifically active road noise and wind noise cancelling in EVs, is even higher than in ICE vehicles. Additionally, EVs have new and unique high-frequency noises created by their drivetrain. Silentium's Quiet Bubble™ (QB™) active noise-cancelling solution with exceptional high-frequency noise reduction capability is the only available technology to reduce drivetrain noises peculiar to EVs.

**Silentium – The Vehicle Visionaries**

In a world where the lines of the subtle nuances of man's relationship with technology are progressively blurred, we are learning to look at technology as more than a convenience. We have grown to trust the data-driven tech-absorbed world in which we live as man’s connection with technology has evolved into a relationship that empowers and protects with each
integration of evolution. Likewise, our vehicles, where we spend so much of our lives, are more than mere means of arriving at our destination but have become an extension of our psyches that provide all those intimate nuances of active communication. Silentium's innovation meets the future world where the solidification of those communications between man and his vehicle will far outreach the simple idea of using a tool – but a unique and special bridge is formed in the relationship between man and his machine.

**Summary**

Silentium’s technology platform offers a unique solution relevant to multiple large and growing markets. The company’s groundbreaking award-winning patented technology and proven highly effective solutions and products enjoy a substantial market appeal and increasing worldwide demand. Today as Silentium focuses on the automotive industry, we offer an improved and holistic acoustics user experience in vehicles that help automotive OEMs in their quest to shift from physical to software-based solutions and provide essential enablers in the CASE revolution of the automotive world. Silentium also boasts a solid framework of operational and advanced development capabilities, which, coupled with a wide variety of addressable markets, applications, and solutions, create a different highly desirable investment opportunity.

Silentium's degree of high innovation and superior advancements in the revolution and development of ANC tech has positioned it as a leading disrupter in the automotive acoustic design arena. From the rich libraries of sensors and integration of existing OEM hardware to addressing CASE elements to ultimately providing an unparalleled end-user experience, Silentium holistic approach and SaaS technology have forever raised the bar on ANC technology.