How Highly Integrated DSPs for Premium Automotive Audio are Redefining the Driving Experience

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This white paper explores the evolution of automotive audio systems and how highly integrated audio digital signal processors (DSPs) are bringing cutting-edge premium audio technology, once limited to luxury vehicles, to entry-level models.

At a glance

Introduction

Whether it's commuting to work, embarking on road trips, or simply running errands, our vehicles have become extensions of our living spaces. As a result, high-quality audio system features, including effective noise cancellation and sound synthesis, are no longer luxuries – they are necessities.

DSPs are at the heart of this transformation, delivering crystal-clear sound and immersive entertainment experiences that make journeys enjoyable and stress-free. These DSPs are specialized systems-on-a-chip (SoCs) designed for digital signal processing that include a DSP core and additional components such as memory, input/output interfaces and control units. Making premium audio technology accessible to all vehicle types necessitates a practical approach to designing these types of audio systems.

In this white paper, I'll discuss the basics of **automotive audio systems**, how various audio features evolved over time, the processing requirements for these features, and considerations when implementing SoCs across vehicle types.

Basics of automotive audio systems

Before discussing processing components and automotive audio system design trends, let's look at the basic components of an automotive audio system. These systems comprise three parts: a head unit, an external amplifier, and speakers, as illustrated in **Figure 1**.

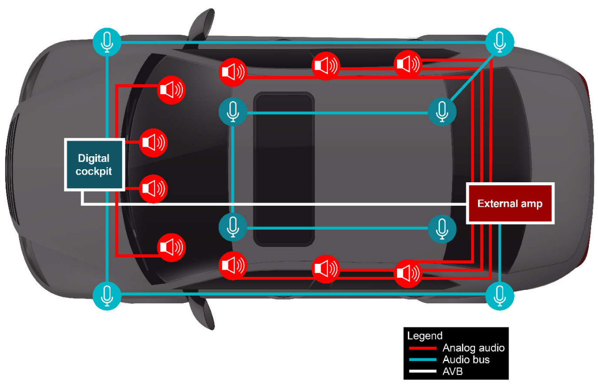

Figure 1. *Standard automotive audio system featuring a head unit, external amplifier and speakers.*

The head unit is a central component of the infotainment system. It manages audio, navigation, connectivity and user interface functions. The head unit receives audio signals from sources such as smartphones, satellite radio, and high-definition radio; processes these signals; and sends them to the amplifier.

The external amplifier strengthens the audio signal processed by the head unit. It makes the sound cleaner and louder. Class D amplifiers have become significantly popular in recent years because of their efficiency and compact form factor.

The speakers convert the amplified signals into audible sound waves.

While a standard automotive audio system can deliver decent sound quality, DSPs for audio processing have revolutionized the way we listen to music in our vehicles. These DSPs enhance sound quality by fine-tuning frequencies, time alignment and levels. A DSP also compensates for speaker limitations and vehicle acoustics, providing precise control and a more balanced, enjoyable listening experience.

Figure 2 through **Figure 4** illustrate three options for the placement of a DSP in an automotive audio system:

- Integration with the head-unit SoC.
- Implementation as a discrete component in the head unit.
- Housing as a discrete component in the external amplifier.

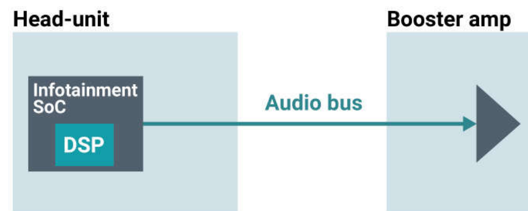

Figure 2. *Simplified diagram of a DSP core integrated in the head unit's main SoC.*

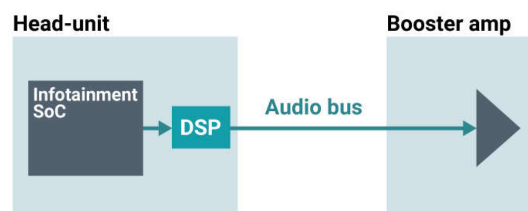

Figure 3. *Simplified diagram of a DSP SoC located inside the head unit, external to the main SoC.*

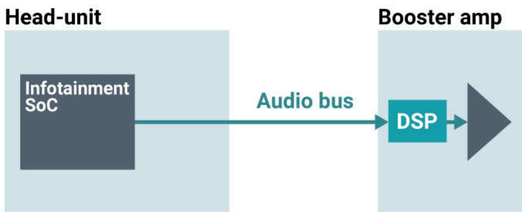

Figure 4. Simplified diagram of a DSP SoC housed in an external amplifier.

Each option has advantages and disadvantages. The most common DSP implementation in current automotive audio systems is in the external amplifier. This approach offers significant benefits, such as decoupling the DSP system design from rapidly evolving head-unit technology. This option also maximizes reusability and scalability and facilitates the rapid advancement of audio systems across a portfolio of in-vehicle infotainment electronic control units (ECUs).

Evolution of automotive audio systems and the need for advanced audio processing

The evolution of automotive audio systems has been remarkable, transitioning from basic mono sound setups to sophisticated 3D audio environments with advanced noise-cancellation technologies. Driven by growing consumer demand for enhanced entertainment options, personalized comfort and safer driving environments, technological progress in embedded processors has made automotive audio system advancements possible.

Let's review the evolution of several audio feature sets and the corresponding SoC capabilities required to meet consumer demand.

Enhanced entertainment with 3D surround sound and increased speaker counts

In its early days, automotive audio systems featured single-speaker mono setups for AM radio. The introduction of FM radio and cassette players brought two-speaker stereo sound to vehicles, enhancing the listening experience. The 2000s saw significant advancements with the introduction of surround-sound systems.

High-end vehicles now include state-of-the-art 3D surround-sound systems, providing an audio experience that makes listeners feel as if they are in a concert hall or movie theater. However, this advanced audio experience comes with a significant increase in real-time computing requirements from the SoC.

Decoding and rendering 3D surround sound or spatial audio requires substantial processing capabilities. To create a three-dimensional soundscape, advanced systems use an array of speakers, including overhead speakers. Features such as sound distribution and personalized audio zones are further increasing the number of speakers in vehicles to 32 or more. Each additional speaker adds to the processing requirements for the dynamic tuning of audio parameters such as equalizer settings, gain and crossover points.

Quieter cabins with active noise cancellation

User comfort, such as a quieter cabin, has also been a primary reason for the evolution of automotive audio systems. Initially, sound-deadening materials such as rubber mats and foam absorbed unwanted sounds from the engine, road, or other noise sources. These passive methods had limitations, however, particularly in handling low-frequency noises, and added weight to the vehicle.

Active noise cancellation (ANC), a significant advancement, uses microphones to detect ambient noise and generates sound waves with opposite phases to cancel out that noise. ANC makes for a quieter and more comfortable ride, as shown in **Figure 5**, and has proven to be crucial in electric and hybrid vehicles, where the absence of engine noise makes road noise more prominent.

Processing complex ANC algorithms such as road noise cancellation (RNC) requires high-performance real-time computing at very low latency to avoid out-of-sync generation of the canceling signal, which can reduce the effectiveness of the noise cancellation.

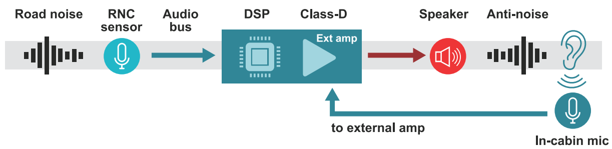

Figure 5. An ANC signal chain based on an embedded processor.

Clarifying conversations among passengers with ICC systems.

In-car communication (ICC) systems significantly enhance the ease and clarity of conversations within vehicles, particularly in larger or noisier environments. By employing strategically placed microphones and advanced DSPs, ICC systems capture and amplify speech, ensuring that passengers can communicate effortlessly without raising their voices or turning their heads. This technology not only improves the overall travel experience but also enhances safety by enabling drivers to maintain their focus on the road. Similar to RNC, ICC features also require very low latency processing to avoid any echo from speaking passengers.

Enhancing safety with sound synthesis and alerts

Given their near-silent operation, the audio systems in hybrid and electric vehicles require features such as engine sound synthesis (ESS) for acoustic vehicle alert systems (AVASs). Hybrid and electric vehicle manufacturers must comply with safety regulations, and have their audio systems produce artificial sounds to alert pedestrians of the vehicle's presence. Future integration of functional safety features is trending toward Automotive Safety Integrity Level (ASIL) A or ASIL B risk classifications from International Organization for Standardization 26262.

Chimes and alerts inside the vehicle have also evolved from simple beeps or tones to alerting drivers and passengers to put on their seat belts, or warn that a door is still open. Advanced driver-assistance system alerts such as lane departure and collision warnings also require audio. As the number of distinct chimes and alerts in a vehicle grows, so does the need for an SoC to support large storage with high-speed access, in order to manage high-resolution audio files and smooth real-time playback without interruptions.

Table 1 summarizes the various audio features of modern vehicles and their processing needs.

Audio Feature Set	High-Performance Real-Time Computing	Low-Latency Processing	High-Speed External Memory	Functional Safety Requirement
3D surround sound	x			
Multiple speaker training	x			
RNC	x	x		
ICC	x	x		
Alerts and chimes			x	
AVAS			x	x

Table 1. Various audio features of modern vehicles and their processing needs.

Selecting the right SoC architecture when designing premium audio systems

Bringing premium audio to all vehicle trim types requires that original equipment manufacturers (OEMs) find ways to reduce overall system costs for their vehicles through scalability. For example, OEMs can develop reusable designs that reduce component and cable count in a compact form factor.

There are three considerations when selecting an SoC for premium audio systems: computing power, memory integration, and the integration of other system components.

Computing power

Two types of cores are popular for audio signal processing:

- **General-purpose CPU cores** that can handle sequential workloads. These cores have great programming flexibility and can execute DSP algorithms; however, they are not cost or power efficient. Typically, these cores are used in low- to mid-end audio systems that require multiple CPU cores to fulfill processing needs.
- **Specialized, power-efficient DSP cores** that can solve millions of complex mathematical problems. These cores process real-time data from audio, vision, radar and sonar sensors, maximizing processing per clock cycle. DSP cores with vector-based architectures tend to deliver higher performance compared to a traditional scalar-based DSP architecture for audio processing. They scale well from low- to high-end digital amplifiers. DSP cores are not easy to program, however, requiring familiarity with DSP hardware features and software optimization techniques to achieve the best performance.

Memory integration

Achieving high-throughput audio processing requires the functional units of a DSP core to access memory every cycle. In a traditional DSP architecture, L1-cached memory supports single-cycle memory access but is very limited in size given its high cost. Designers are now looking for innovative DSP memory architectures where single-cycle accessible memory size is not constrained to L1 memory limits.

Designers also prefer DDR-less design with an SoC that has sufficient static random-access memory (SRAM) size that can meet their entire application memory needs. However, SoCs integrates limited SRAM size as they are costly. It is not always feasible to fit entire audio application in DDR-less SoC given the growing memory needs of advanced feature sets such as artificial intelligence (AI)-based algorithms or sound synthesis with high-resolution audio files. Therefore, along with SRAM, designers also need SoCs with scalable memory options such as high-speed low-power double-data-rate (DDR) dynamic RAM.

Integration of other system components

Along with a DSP, a premium audio system needs additional components to meet safety and security requirements, as well to interact with rest of the system.

A microcontroller is necessary to comply with automotive safety features, and to run Automotive Open System Architecture (AUTOSAR), which is an open and standardized software architecture designed to help facilitate the integration of the DSP with the rest of the system.

A hardware security module, cryptographic acceleration and other components can help fulfill security requirements of the E-Safety Vehicle Intrusion Protected Applications (EVITA) standard.

A low-latency audio network will handle the precise communication and synchronization of audio signals between automotive audio system components. Among different technologies that need additional cables, the Ethernet Audio Video Bridging (AVB) standard is a perfect choice, as Ethernet cables already exist in the vehicle for connecting other ECUs, thus simplifying wiring architectures and reducing overall system cable weight and system cost.

Furthermore, pin-to-pin compatible SoCs with scalable DSP performance and memory choices can bring efficiency to audio designs by reducing R&D investment for premium automotive audio systems.

Designing a premium audio system with TI DSPs

TI created its automotive audio DSP portfolio to address premium automotive audio system design challenges and help engineers achieve scalable audio performance at an affordable system cost. With our highly-integrated pin-to-pin compatible audio SoC family, premium audio is no longer exclusive to higher-end vehicles. Designers can use a single chip to deliver an immersive audio experience across entry-level to high-end systems. The result is a quieter cabin, with high-quality sound rivaling that of an expensive home theater system.

These highly integrated SoCs, including TI **AM2754-Q1 MCUs** and **AM62D-Q1 processors**, help reduce the number of components required for an automotive audio amplifier system by integrating TI's vector-based C7x DSP core, neural processing unit for edge AI processing, Arm® Cortex®-R5s MCUs, optional Cortex-A53 cores, memory, a two-port Ethernet switch with Time-Sensitive Networking, and a hardware security module (HSM) into an International Organization for Standardization (ISO) 26262 TI Functional Safety-Compliant targeted SoC. Integrated SoCs make it possible to reduce the number of components and therefore the bill of materials, thus making it easier and more affordable to design premium audio systems.

The C7x DSP core in TI DSP audio processors provides more than four times the processing performance of traditional scalar-based audio DSPs. Pairing the C7x core with a matrix multiply accelerator forms an on-chip NPU that can process both traditional and edge AI-based audio algorithms. This performance enables the management of multiple premium audio features within a single SoC rather than using multiple SoCs.

Additionally, the SoCs provide scalable memory options that give audio engineers the flexibility to design for a range of systems using TI's single audio processing platform. The AM2754 is a DDR-less MCU designed for the highest audio computing capability. The MCU's memory architecture is based on up to 4.5MB, single-cycle access L2 memory and up to 6MB of L3 memory. The AM62D-Q1 is a DDR-based processor meant for premium audio designs that require high-speed external memory. The AM62D's memory architecture includes 1.25 MB of single-cycle access L2 memory, and a 32-bit LPDDR4 controller for additional high-speed external memory.

The on-chip Arm Cortex-R5 MCU cores reduce the need for external, discrete MCUs to support AUTOSAR software (as an industry-standard core, AUTOSAR software is readily available from third-parties). ISO 26262-targeted SoCs further enable futureproofing of system designs with the evolving audio functional safety requirements of AVAS-like features.

An HSM with integrated secure storage, cryptographic hardware acceleration, a secure CPU and a hardware interface to the rest of the system fulfills the highest-level requirements of Secure Hardware Extension 1.1 and the EVITA standard.

An integrated Ethernet switch with hardware-supported Time-Sensitive Networking and other features enable an Ethernet AVB solution for audio networking. **Figure 6** shows the integrated components of TI's automotive audio embedded processors.

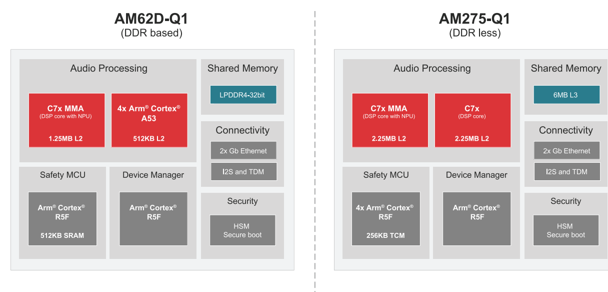

Figure 6. *AM2754-Q1 and AM62D-Q1 high-level integration.*

Conclusion

Automotive audio has come a long way from its humble beginnings, evolving into a sophisticated system that enhances the driving experience. Whether you're a casual listener or an audiophile, there's no denying the impact of these advancements on our daily commutes and road trips. Selecting the right SoC architecture for audio makes it possible to transform every vehicle into a personal concert hall, where each beat has perfect clarity and precision.

Additional resources

- Read the technical article, "**Designing an Efficient Automotive Premium Audio System with Highly Integrated Processors**."
- Check out TI's full range of **end-to-end audio solutions**, including amplifiers, processors, converters and switches.
- Learn how advanced semiconductors, like TI's automotive audio DSPs, are enhancing the driving experience in the TI Company Blog article, "**Redefining the commute: The advanced audio technology transforming your drive**."

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