

## THE ROLE OF A VEHICLE'S ELECTRICAL SYSTEM IN THE FUNCTIONING OF HIGH-QUALITY CAR AUDIO

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### ABSTRACT

This study examines the impact of various automotive components, including alternators, batteries, cable connections, and grounding circuits, on the performance of amplifiers and acoustic systems. The vehicle's electrical system is considered a key factor influencing the functionality of an audio system. The objective of this study is to identify the factors affecting audio equipment parameters and develop recommendations for their improvement.

The study incorporates publications by international researchers focusing on the role of the vehicle's electrical system in ensuring audio quality, as well as an industry report by McKinsey.

The findings indicate that voltage fluctuations and electromagnetic interference (EMI) have a significant impact on sound reproduction quality. The use of high-performance alternators, modern battery systems, thick-gauge cables, and shielded wiring has been shown to enhance the parameters of an in-car audio system. Recommendations have been developed for implementing modern approaches to improve car audio performance.

The conclusion highlights the importance of designing a vehicle's electrical infrastructure to achieve high-performance audio systems. The information and recommendations presented in this study may be of interest to professionals in automotive electronics, audio equipment specialists, and engineers.

**Keywords:** Automotive Electrical Network, Car Audio, Alternator, Electromagnetic Interference, Grounding, Amplifier, Digital Signal Processing.

### I. INTRODUCTION

Automotive audio systems are designed to deliver high-quality sound in the confined space of a vehicle cabin. Their performance depends on the parameters of the electrical network, which ensures stable power supply, reduces interference, and maintains energy efficiency. The integration of new technological solutions makes this topic relevant for scientific publications focused on optimizing automotive electronics.

The McKinsey report "Technology Trends Outlook 2024" [10] highlights key technological trends shaping the future of various industries, including the automotive sector. Among the most significant developments are artificial intelligence (both generative and applied), cloud and edge computing, 5G, and electrification technologies. These innovations aim to create more intelligent, efficient, and sustainable systems, directly affecting the integration of new technologies into automotive platforms.

Scientific research on the interaction between a vehicle's electrical system and audio equipment covers a wide range of aspects, including sound processing, acoustic analysis, and the elimination of electromagnetic interference. Studies on sound formation emphasize the perception of acoustic parameters. Yu S. et al. [1] analyze algorithms used in electric vehicles, demonstrating their role in generating unique sound effects. Lin J. et al. [2] examine frequency ranges suitable for automotive applications, emphasizing their influence on in-cabin sound quality.

Back J. et al. [3] propose methodologies aimed at improving acoustic comfort within the cabin. Shively R. [6], in analyzing the development of automotive audio technologies, provides an overview that identifies trends and forecasts prospects in this field.

In electric vehicles equipped with high-voltage circuits, minimizing their impact on audio performance requires a specialized approach. Tang K. et al. [9] highlight the need to reduce interference to ensure stable audio system operation.

Mody M. et al. [5] present methods utilizing microcontrollers for audio signal processing, reducing energy consumption while enhancing sound quality. Espinosa Loera R. A. et al. [8] explore the potential of data analysis algorithms and describe approaches applied to optimizing acoustic characteristics.

Zhang S. et al. [4] investigate methods for suppressing external noise to create a more comfortable auditory environment. De Cesaris S., Würsig A., and Schirmacher [7] propose solutions for improving audio system performance by mitigating electrical interference.

Thus, scientific research demonstrates a variety of approaches to creating an optimal in-vehicle acoustic environment. The issue of eliminating electromagnetic interference requires further investigation, as does the integration of innovative sound processing methods. Another promising area is the development of approaches tailored to the driver's auditory comfort. Addressing these challenges successfully requires a combination of technical advancements and methodologies aimed at enhancing user experience with automotive audio systems.

The objective of this study is to identify factors affecting audio equipment parameters and to develop recommendations for their improvement.

The scientific novelty lies in the systematic analysis of the interaction between a vehicle's electrical system and car audio components, which enables the development of new approaches to enhancing the stability of audio system power supply.

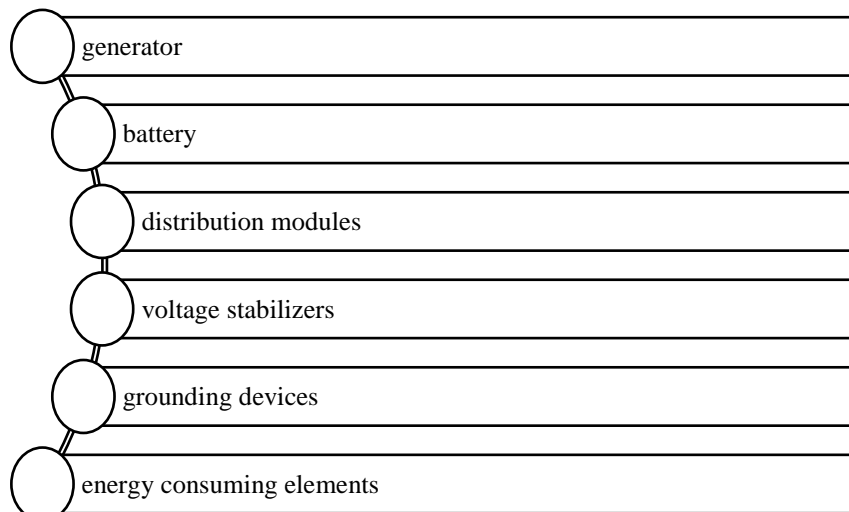
The research hypothesis suggests that improving car audio quality is achievable through the modernization of vehicle electrical system components.

The research methodology is based on a comparative analysis of scientific publications as well as the McKinsey industry report.

## II. RESULTS

In recent years, key trends influencing various industries, including the automotive sector, have been the development of generative artificial intelligence and electrification. Generative AI has advanced rapidly, driving an increase in computing power, expanding data processing capabilities, and improving multimedia technologies. The electrification of vehicles has progressed, with an increasing reliance on renewable energy sources, which has impacted the enhancement of automotive audio systems [10].

The electrical systems of vehicles regulate the distribution of power across various components, converting mechanical energy from the engine into electrical energy and distributing it to the necessary subsystems. The components that make up this system are visually represented in Figure 1 for clarity. This infrastructure operates under variable loads, making it challenging to maintain stable parameters. Fluctuations in power distribution create obstacles for audio systems, which require precise adherence to technical specifications [7].



**Figure 1:** Components of a vehicle's electrical system [1,3,6].

The system's primary function is to provide stable power supply to all devices, ranging from the safety management system to lighting. The electrical network operates during vehicle startup and throughout its operation, ensuring the required voltage for the uninterrupted functioning of all installed mechanisms. The battery and generator maintain voltage levels throughout the vehicle's lifecycle.

With technological advancements, the electrical system has become more complex, incorporating automation elements and driver assistance systems. Modern vehicles are equipped with sensors, autonomous driving devices, and active safety systems, which impose high demands on the stability of the electrical network. These innovations enhance convenience and safety while significantly increasing the system's load.

The operating principle of the electrical system involves converting mechanical energy into electrical energy through the generator. When the engine is running, its rotation drives the generator, which produces electrical energy. This energy is then supplied to the battery, where it is stored for later use and distributed across the vehicle's components. The generator ensures continuous charging of the battery while the vehicle is in motion.

When the engine is off, the battery supplies power to electrical devices, including the starter, which is essential for engine ignition. The electrical system manages power distribution through relays and fuses. In case of overload or short circuits, fuses break the circuit, preventing damage. The onboard computer monitors the system's condition, regulates power distribution, and manages load balancing. This control prevents overloads and ensures the stable operation of all vehicle components [9].

The proper functioning of the electrical system relies on the organized flow of electricity, transmitted from power sources through conductive elements to consumers. A closed circuit ensures stable energy transfer. The interconnection of these components establishes a reliable and secure system operation.

The generator serves as the primary power source while the vehicle is in motion. Audio equipment, including amplifiers and subwoofers, imposes significant demands on the electrical infrastructure. When combined with lighting systems and climate control, the generator load increases significantly. If the generator's output is insufficient, voltage drops occur, leading to sound distortions, reduced volume, and component shutdowns.

The battery acts as an energy buffer, compensating for temporary deficits during peak loads. During the playback of music with intense low-frequency elements, the system experiences a substantial increase in power consumption. In such situations, the battery stabilizes the voltage level. Standard batteries are unsuitable for sustaining high loads over extended periods. Automotive audio systems often use high-performance batteries designed for durability and stability under high current loads.

Wiring plays a critical role in ensuring the proper operation of equipment. Cables with larger cross-sections minimize power loss and provide efficient electricity transmission without overheating. Grounding must be carefully executed, as insufficient attention to this aspect can cause noise and acoustic distortions. To eliminate these issues, conductors are used to connect the primary elements of the electrical system.

Interference generated during system operation degrades sound quality. Voltage fluctuations caused by the generator, ignition system, or other devices lead to unwanted noise. To counteract these effects, voltage stabilizers, filters, and shielded cables are used to protect the system from electromagnetic interference.

Capacitors are employed for short-term energy storage, compensating for power surges and maintaining system stability. These devices are particularly useful in setups featuring high-power subwoofers.

Additional batteries are positioned closer to amplifiers, reducing cable length and minimizing energy losses. In exhibitions or competitions, external power sources are used to ensure stable voltage levels [2]. Table 1 below outlines measures aimed at reducing the negative impact of external factors on the sound quality of audio systems.

**Table 1.** Measures to reduce the impact of adverse factors on car audio system sound quality [1,2,6]

Measures	Impact Description	Effect of Implementation	Development Trends	Implementation Methods
Use of energy storage devices	Capacitors eliminate voltage fluctuations caused by loads. Placing them near amplifiers reduces energy losses.	Elimination of voltage fluctuations, reduction of energy losses, increased equipment stability.	Development of compact supercapacitors with increased capacity and durability.	Use of intelligent management systems for automatic activation and deactivation of energy storage devices as needed.
Use of high-quality conductors	Copper or silver wires, properly selected by cross-section, minimize losses, prevent cable overheating, and maintain system stability.	Reduction of energy losses, prevention of cable overheating, increased system reliability and durability.	Transition to the use of nanowires and new materials such as graphene to enhance conductivity and strength.	Gradual modernization of existing networks using new materials.
Shielding of data transmission lines	Cables protected from external interference through shielding isolate electrical signals and prevent the influence of electromagnetic disturbances.	Protection against electromagnetic interference, improved signal quality, reliable data transmission.	Development of cables with active shielding and enhanced noise suppression properties.	Integration of shielding into manufacturing processes, use of hybrid cables with protective coatings.
Additional power sources	Additional batteries installed for energy-intensive systems offload the generator, ensuring stable operation.	Stable system operation, reduced load on primary power sources.	Use of next-generation batteries (solid-state, graphene), integration with renewable energy sources.	Development of modular power supply systems with the capability for quick connection and replacement of additional sources.

The efficiency of amplifiers is determined by voltage stability and the power supply's ability to handle peak loads. Insufficient energy results in effects that distort sound characteristics. To prevent these issues, devices that compensate for voltage fluctuations are used.

Grounding circuits play a key role in eliminating stray currents. Errors in their design lead to noise generation. Reducing conductor length and consolidating connections at a single point improves performance [4]. Table 2 below describes the role of the vehicle's electrical system.

**Table 2.** The role of a vehicle's electrical system in high-quality car audio performance [5,7,8].

Section	Description	Key Parameters	Issues Due to Deficiencies	Recommendations
Battery	The primary power source for the audio system when the engine is off.	Capacity (Ah), cranking current, quality of components.	Insufficient power for amplifiers, reduced sound output.	Use a high-capacity battery with low internal resistance.
Alternator	Generates energy to power the audio system while the engine is running.	Power output (W), voltage stability, reliability.	Insufficient voltage, sound dips when volume increases.	Upgrade to a higher-output alternator or install an additional one.
Wiring and connectors	Transfers electrical energy from the alternator and battery to the audio system.	Cable gauge, material quality, conductivity.	Energy loss, interference, wire overheating.	Use thick-gauge copper wires and high-quality connectors.
Capacitors (Power Supply Stabilizers)	Stabilize power for amplifiers, preventing voltage drops under heavy loads.	Capacitance, voltage rating, response speed.	Loss of dynamics, sound distortion, amplifier overload.	Install high-quality audiophile-grade capacitors.
Interference protection	Eliminates electromagnetic and radio frequency interference affecting sound quality.	Shielded cables, filters, grounding.	Noise, crackling, sound distortion.	Use shielded cables, proper grounding, and power line filters.

To enhance car audio quality, upgrading the vehicle's electrical system is essential for stable power delivery to audio components. The first step is installing a high-capacity battery capable of handling increased current loads required by amplifiers and other system components. This prevents voltage fluctuations and ensures uninterrupted system operation.

The second aspect is selecting proper wiring. Low-resistance, thick-gauge cables help reduce energy losses and improve signal transmission from audio sources to amplifiers and speakers. To mitigate electromagnetic interference, filters and voltage stabilizers should be installed to maintain signal purity.

The third step involves improving the grounding system. Proper grounding reduces noise and interference, which is crucial for high-power amplifiers and sensitive components. Additional grounding points, high-quality connections, and low-resistance cables enhance overall performance.

The fourth step is installing an additional alternator. It ensures stable voltage levels even under heavy loads, which is critical for high-performance audio systems. A standard alternator is often insufficient for maintaining system stability without degrading sound quality.

### III. CONCLUSION

Unstable voltage caused by fluctuations in alternator power output affects acoustic accuracy and increases distortion. To mitigate these effects, the use of high-performance alternators and energy storage devices capable of compensating for load surges is recommended. Electromagnetic disturbances occurring in the vehicle's onboard circuits negatively impact sound characteristics. To eliminate these issues, shielded cables and power system filters should be utilized. A well-designed grounding system prevents unwanted currents that could degrade overall system performance.

Modern signal processing technologies and energy management systems enable seamless integration of audio equipment with automotive electronics, ensuring stable operation even under high load conditions.

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