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The Magnetic Application in the Loudspeaker and Headset

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Abstract: Loudspeakers and headsets are ubiquitous electronic devices essential to modern life, finding extensive applications in medicine, education, entertainment, and communication. This paper explores their fundamental operating principles, rooted in electromagnetic and acoustic theories, and provides a comprehensive analysis of their mechanisms. It summarizes various optimization strategies aimed at enhancing performance, including advancements in acoustic output, material innovations like carbon nanotubes, structural design improvements, and computational efficiency through algorithms such as adaptive impedance matching and genetic algorithms. The study also addresses current challenges faced by these devices, such as the trade-off between miniaturization and sound quality, escalating production costs, limited battery life, and issues related to prolonged user comfort. Furthermore, it highlights evolving user expectations for higher sound quality, longer battery life, and more ergonomic designs. By synthesizing existing research and forecasting future trends, the paper offers valuable insights into the ongoing development of loudspeakers and headsets, anticipating that innovations in artificial intelligence, smart materials, and personalized audio technology will significantly shape their future evolution.

Keywords: Loudspeaker, headset, principle, optimization

1. Introduction

As the key equipment of sound transmission, loudspeaker is widely used in many fields. For example, in education, speakers are used to design educational toys, such as electroacoustic clarinet, which is connected to a chamber through a speaker and uses a positive feedback mechanism to generate self-excited oscillations to achieve amplification of sound [1]. In behavioral neuroscience research, high-precision audio stimulation systems are needed, so a low-cost, open-source auditory delivery system has been developed that includes a high-fidelity sound card and a low-latency audio amplification device capable of providing high-quality sound output [2].

In the part of headset, with the popularity of portable audio devices such as smartphones and music players, people are increasingly listening to music or watching videos through headsets. However, using headsets at high volume for long periods of time may lead to noise-induced hearing loss. Therefore, it is particularly important to study the effect of headsets on hearing and its potential risks [3]. In addition, modern headsets are not limited to entertainment use, but also play an important role in health monitoring and medical assistance. For example, some smart headsets are able to monitor physiological parameters such as heart rate and blood pressure, and are even used for early screening and rehabilitation of hearing disorders [4, 5].

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Loudspeakers and headsets have long been popular products in life, this paper mainly describes the basic principles of loudspeakers and headsets, as well as researchers on the optimization of loudspeakers and headsets. In addition, there are the author's expectations for the development of loudspeakers and headsets.

2. Loudspeakers Analysis

Loudspeaker is an acoustic device that converts electrical signals into sound signals, and is widely used in communication, entertainment and so on. The working principle of the loudspeaker is based on the basic laws of electromagnetism, through the structural design and electromagnetic interaction to achieve the conversion between electrical energy and sound energy. In-depth study of the principle of loudspeaker is of great help to the optimization of loudspeaker.

2.1. Basic principle of loudspeaker

The structure of the loudspeaker is mainly composed of permanent magnet, voice coil and diaphragm which is shown in Figure 1.

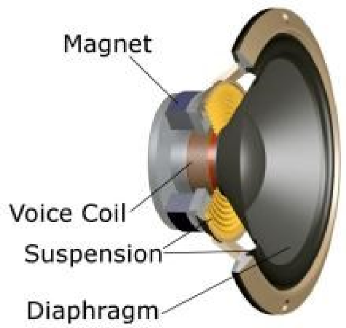

Figure 1: The structure of the loudspeaker

The basic working principle of a loudspeaker involves converting electrical signals into mechanical vibrations that produce sound. This process is usually achieved through electromagnetic induction, in which an electric current pass through a coil creating a magnetic field that interacts with the magnetic field of a permanent magnet, causing the coil (and its attached diaphragm) to move back and forth, which in turn pushes the air to produce sound waves [6]. The permanent magnet provides a stable magnetic field in which the voice coil is connected to the diaphragm. The two are connected in a way that ensures both firmness and no additional interference during movement. When the audio current passes through the voice coil, according to the principle of electromagnetic induction, the voice coil will be subjected to the ampere force in the magnetic field. Because the audio current changes with time, the amperage force received by the voice coil will also change accordingly, which will drive the diaphragm vibration. The vibration of the diaphragm will cause the vibration of the surrounding air, and then generate sound waves to achieve the conversion of electrical signals to acoustic signals. In simple terms, the speaker has a fixed permanent magnet and a movable coil inside. When the audio signal passes through the coil, the coil is affected by the magnetic field generated by the magnet, which creates a push and pull motion. This motion is transmitted to the diaphragm, which in turn pushes the surrounding air molecules further, creating sound waves [6, 7]. In addition, the working principle of different types of speakers may adopt different, such as electric speakers, electrostatic loudspeaker and piezoelectric speaker, etc. Each speaker has its own specific design and application scenario [7].

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2.2. Optimization of loudspeaker

Previous research on loudspeaker optimization mainly focuses on improving loudspeaker performance, reducing distortion and enhancing sound quality. At present, the optimization methods include acoustic environment optimization, frequency response optimization, loudspeaker unit optimization and power and resistance matching. The acoustic environment optimization of loudspeakers is mainly achieved through mathematical optimization techniques designed to maximize the acoustic transmission index (STI) at the receiving end or to reduce the impact of ambient noise. For example, in the literature [8], an optimization algorithm for repositioning the receiver in an indoor environment based on sound propagation characteristics is proposed to maximize STI. In another paper [9], a new acoustic discrete optimization algorithm is introduced for source placement to reduce ambient noise. The algorithm improves the quality of the acoustic environment by optimizing the position of the loudspeaker. In order to verify the effectiveness of the optimization method, the researchers conducted a variety of experiments. For example, the researchers tested their algorithm in different indoor environments and assessed how the STI changed [8]; their acoustic design optimization algorithm is tested by simulation and real scene, especially focusing on the effect of source placement on noise reduction [9]. Finally, it is concluded that the STI can be effectively improved by repositioning the receiver, thus improving the sound quality and the use of acoustic discrete optimization algorithm for source placement can effectively reduce environmental noise and improve the overall performance of the acoustic environment [8, 9].

Methods and techniques in frequency response optimization are mainly density-based material optimization, finite element model (FE model) and filter optimization [10-12]. The researchers used density-based material optimization methods to improve the speaker's low-frequency performance. By optimizing the material distribution of the loudspeaker system, the response of the loudspeaker in the low frequency band is smoother and more stable [10]. In terms of finite element models (FE models), finite element models are used to optimize the frequency response of loudspeakers. By simulating speaker performance at different frequencies, it can be found that the performance of the speaker in the low band is significantly improved [11]. In the aspect of filter optimization, a method to optimize the frequency response of the filter is proposed. By calculating the filter coefficient by inverse Fourier transform, the frequency response of the loudspeaker can be equalized effectively, so that it is closer to the target response curve [12].

In terms of the material of the diaphragm and the voice coil, carbon nanotube (CNT) based diaphragm is also used to improve the acoustic output of loudspeakers [13]. The physical properties of materials can be improved by heat treatment and other methods. For example, the diaphragm material is heated in an oven to form the surround structure of the speaker, which is then attached to the diaphragm and the voice coil [13]. In the optimization of power and resistance matching. First, an adaptive impedance matching (AIM) system is used to dynamically adjust the impedance through a fast optimization algorithm to adapt to different transmission distances and environmental conditions [14]. In addition, there is another way to reduce the reflected sound energy and improve the absorption efficiency of sound energy by optimizing the energy transmission path [15].

2.3. Loudspeaker’s challenges

Today's loudspeakers on the market mainly face the contradiction between small size and treble quality. As the size of electronic products tends to be smaller and thinner, miniature speakers are becoming more common. At the same time, sound quality is limited by the reduction and reduction of components within the speaker. The smaller the sound, the higher the resonant frequency, resulting in bass attenuation, weak sound performance, difficult to meet consumer requirements for treble quality.

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Loudspeaker manufacturers are also facing the pressure of cost control, raw material price fluctuations, rising labor costs and other factors to the speaker companies caused great pressure. How to reduce costs under the premise of ensuring speaker performance is an important challenge for enterprises to face.

3. Headsets Analysis

Headset is also a common audio player, it reduces the outside noise interference through technology, so that people pay more attention to audio content, today's society headset has become an important tool for people to enjoy audio and convenient communication.

3.1. Basic principle of headset

The basic principle of headset is also to convert electrical signals into sound. This is usually done by a dynamic drive unit consisting of a permanent magnet, coil and diaphragm. When the audio signal (electrical signal) passes through the coil, it creates a changing magnetic field, which in turn causes the diaphragm to vibrate and produce sound [14, 16]. In addition to the dynamic drive unit, there are many types such as electrostatic and planar magnetic, but the dynamic drive unit is widely used because of its low cost and stable performance. The main components of the headset are the drive unit, headband, ear muffs, cables and interfaces, and control unit. Among them, the driving unit is responsible for converting the electrical signal into the acoustic signal; the headband is used to fix the position of the headset to ensure wearing comfort; in ear cover has two styles, one is open earmuffs and enclosed earmuffs, open earmuffs allow voice better spread, provide more natural feeling, enclosed earmuffs can effectively isolate external noise, suitable for a noisy environment [17]. Cables and ports are used to connect headset and audio source devices. Common ports include 3.5mm jack and USB, the control unit refers to the volume adjustment button, microphone switch, etc., in some high-end headset [16].

3.2. Optimization of headset

The optimization of the headset mainly focuses on acoustic performance, physical design, computational efficiency, and personalized experience. Acoustic performance includes sound quality, noise reduction effect, frequency response and so on [18]. In this regard, the researchers propose H2/H∞ methods (using traditional H2/H∞ methods to optimize the feedback controller of ANC headsets to improve noise reduction), genetic algorithms (genetic algorithm-based optimization methods to optimize the loudness and pressure level (SPL) of headsets) [19].

A multi-objective optimization method is proposed to improve acoustic performance. Headset physical design optimization including but not limited to pressure distribution optimization earmuffs are optimized by the simulation to objectively evaluate the pressure distribution in the wearing comfort of headsets. This method can effectively reduce the discomfort when wearing headsets for a long time, smart headset design makes the headset intelligent without adding extra sensors, acoustic shielding optimization headphones provide a consistent hearing experience in different environments, echo virtualization design in maximizing the realism of the headset in a virtual environment [20-23].

In terms of the optimization of the computing efficiency of the headset, researchers have adopted a variety of methods and techniques. First, a system optimization technique is proposed that is designed to minimize computational costs to achieve real-time surround sound effects [24]. In addition, there are studies to optimize the hardware architecture to achieve efficient adaptive algorithms, so as to improve computing efficiency [25]. For example, in one study, researchers optimized the filter length of the FxLMS adaptive algorithm and proposed an efficient hardware architecture for implementing high-fidelity in-ear headsets [25]. In addition, there are studies to

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improve the computational efficiency of headphone systems through parallel computing techniques. For example, some studies discussed the design and implementation of the headset system based on the CUDA environment, analyzed the specific computing aspects, and significantly improved the computing speed through parallel operation [26]. Another study explored how to efficiently implement auditory penetration in headphone systems by optimizing filter design to make this function more efficient [27]. Finally, there are a number of studies that focus on noise control in headsets to improve computational efficiency by optimizing the design of feedback controllers. For example, some studies have proposed a two-stage optimization strategy to design a fixed feedback controller directly on an active noise-reduction headset in combination with genetic algorithms, which effectively improves the computational efficiency of noise control [28].

In terms of the personalized experience of headsets, many studies have pointed out that the use of personalized HRTFS can significantly improve the realism of spatial sound effects. For example, some studies measure the ear shape of an individual to generate a personalized HRTF model to enhance the user experience [19]. Secondly, the sound output of the headset is optimized by the algorithm to make it more in line with the user's listening habits [29]. Third, motion sensors are integrated in some high-end headsets, which can dynamically adjust the sound according to the user's head movement, providing a more immersive experience [30]. Finally, in the aspect of environmental noise management, active noise reduction technology and intelligent management of environmental noise can improve the user's hearing comfort in different environments [22].

3.3. Headset’s challenges

In the life experience of the headset, the battery life of the headset is one of the main problems facing the optimization of the headset. Because battery technology is limited, the volume of the headset is small, resulting in limited battery capacity, and users are increasingly demanding for the battery life of the headset. The current headset still has a certain bottleneck in terms of energy density and charging speed, and cannot meet the user's long-term battery life requirements. Need to develop higher performance batteries or new energy batteries to solve.

The comfort of headsets is also a great challenge for the manufacture of headsets. The two types of headsets that are widely available on the market, in-ear headphones may cause compression of the ear canal, and head-mounted headsets may cause a burden on the head and cause discomfort when worn for a long time. More comfortable materials and structures are needed.

4. Conclusion

Loudspeakers and headsets are widely used as electronic devices in People's Daily life. The principle is simple, but nowadays, people's demand for speakers and headphones has become more and more, and many problems have gradually been derived. At the same time, loudspeaker and headset are also constantly being optimized, with the development of science and technology, the user's ideal loudspeaker and headset will be developed.

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