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IMPROVING MEASUREMENTS IN AUDIOLOGY USING ELECTROSTATIC TRANSDUCERS

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Abstract: This paper presents a novel approach to refining the parameters of electro-acoustical transducers aimed at achieving the highest quality, most precise sound reproduction, with a primary focus on over ear headphones. It outlines the motivations, objectives, and outcomes of the research dedicated to creating a new type of electrostatic headphone system, usable in measurement systems for audiology applications. Achieving accurate design for electro-acoustic transducers it is crucial to control the frequency, phase, and polar responses of the headphone systems. Most audio devices on the market, even for audiology measurements tend to prioritize frequency response, with varying levels of success. The more linear behavior of the newly developed headphone system is demonstrated through various measurement techniques and listening tests.
Key words: Electro-acoustic sound reproduction, Audiology measurements, DSP processing.

INTRODUCTION

Headphones and transducers play a pivotal role in the field of audiology, serving as the primary interface for sound delivery during diagnostic testing, hearing assessments, and auditory research. Accurate and reliable frequency response is crucial for these applications, as it directly influences the precision of audiometric measurements. Ideally, headphones used in audiology should exhibit a linear frequency response—where each frequency is reproduced at the same level relative to its input—ensuring that sound measurements are consistent and true to the intended signal [1]. However, most commercially available audiometric headphones and transducers suffer from significant nonlinearities in their frequency response, leading to distortion and inaccuracies in the transmitted sound across different frequency ranges [2].
The most commonly used headphones in audiological testing include circumaural and supra-aural models.
Popular examples of circumaural headphones include:
Sennheiser HDA 200 and Telephonics TDH-39, both of which are frequently used in clinical environments due to their durability and broad frequency range in this category [3].

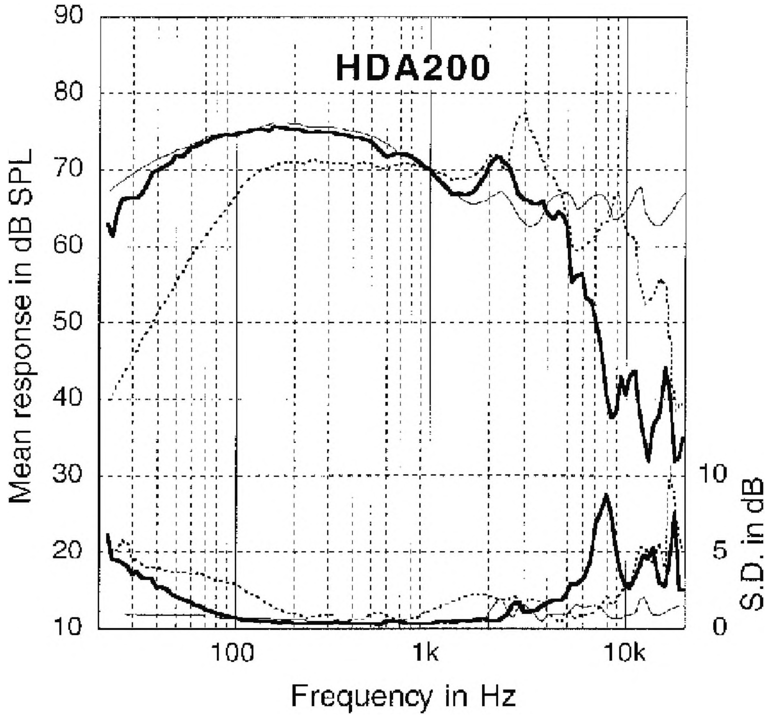

Fig. 1. *Sennheiser HAD 200 Frequency Response [3]*

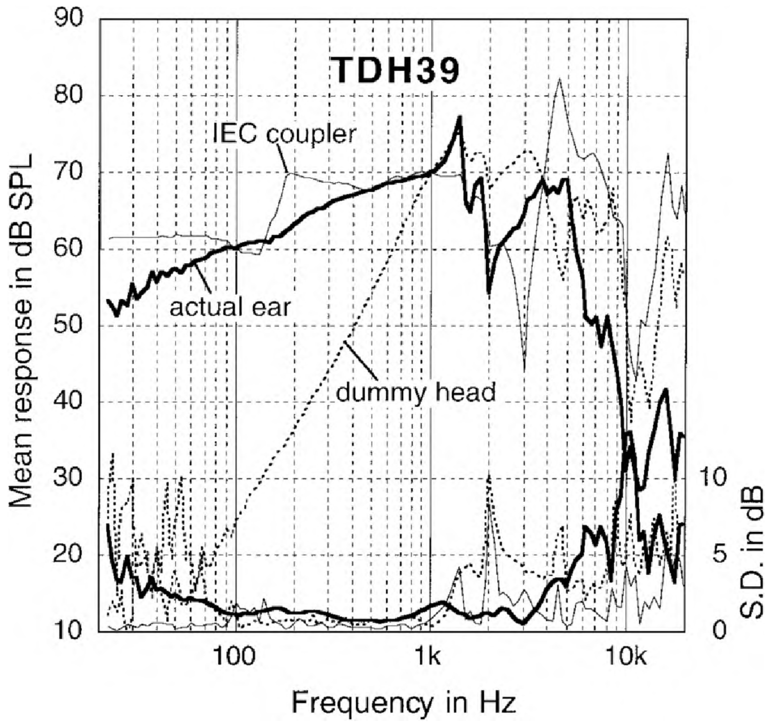

Fig. 2. *Telephonics TDH-39 Frequency Response [3]*

Supra-aural models like the AKG K701, Sennheiser HD 202 and Beyerdynamic DT 770 are also widely utilized for audiometric evaluations, particularly in research settings where precision is paramount. Despite their widespread use, all of these headphones exhibit varying degrees of frequency response nonlinearity, especially at the extreme ends of the frequency spectrum, where inaccuracies become more pronounced [4].

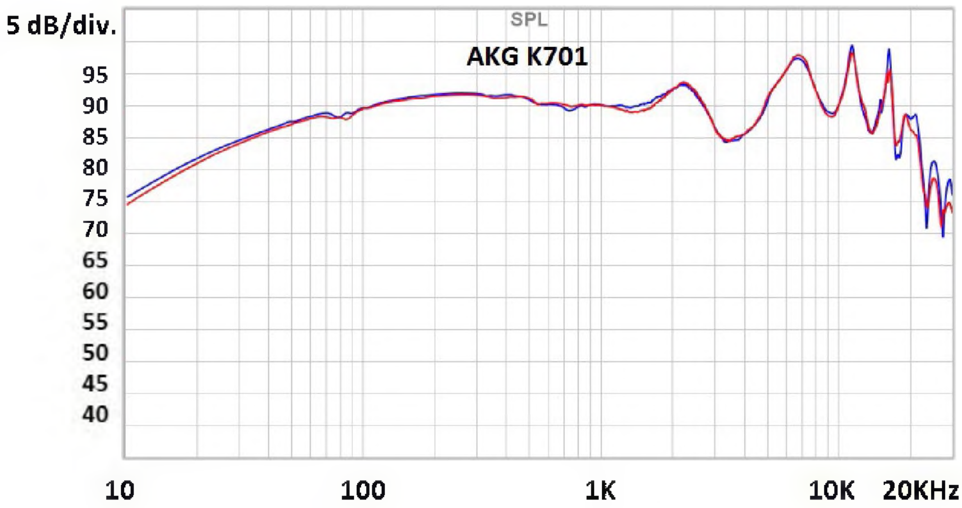

Fig. 3. *AKG K701 Frequency Response [4]*

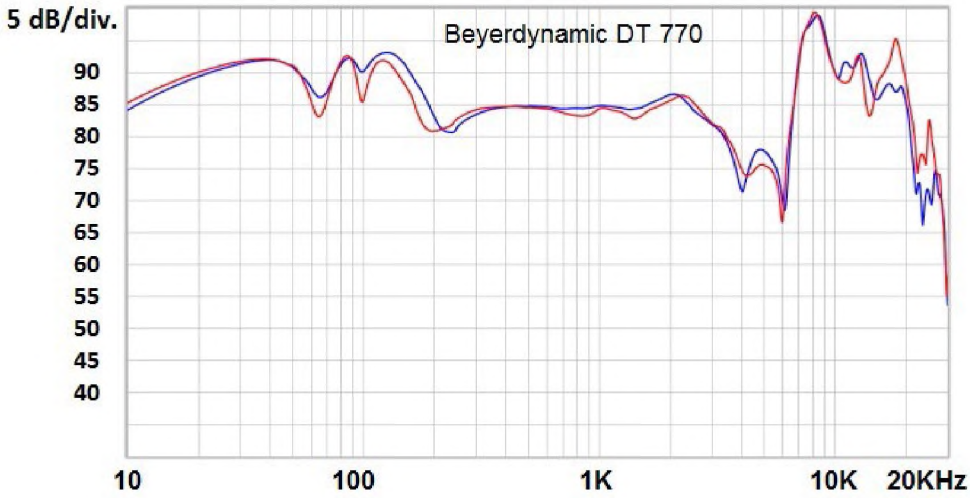

Fig. 4. *Beyerdynamic DT 770 Frequency Response [4]*

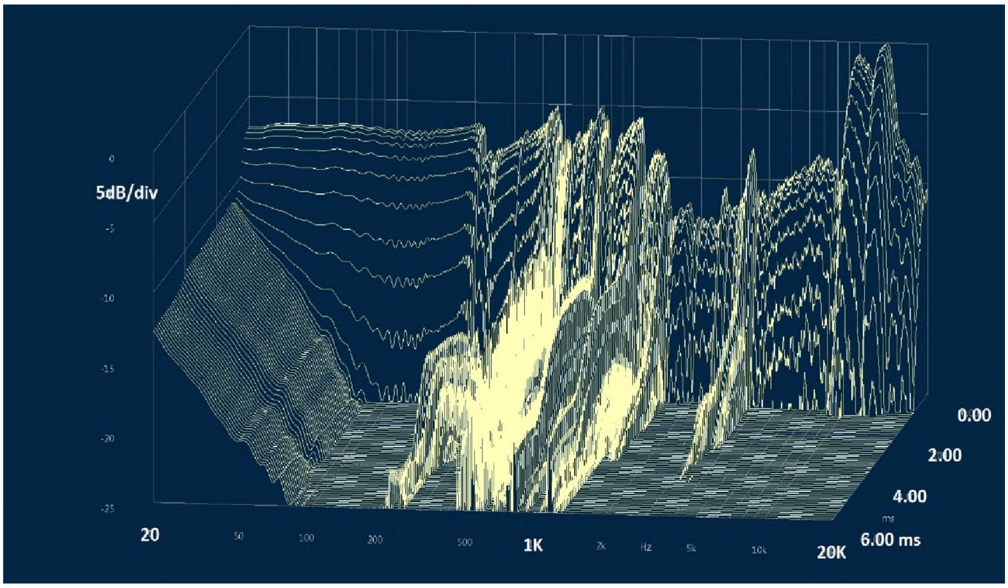

Fig. 5. *Hifiman Susvara Waterfall diagram (Impulse response)*

The challenge posed by these nonlinearities is not merely a matter of poor sound quality, but rather one of compromised measurement precision [5]. In audiological testing, even subtle deviations in the frequency response can lead to skewed thresholds, incorrect diagnosis, and invalid results. To mitigate these issues, modern measurement systems incorporate built-in electronic correction algorithms designed to compensate for the nonlinearity of headphone transducers using DSP processing or software correction methods [6]. These corrections adjust the signals before they reach the headphones, theoretically compensating for any known distortion profiles. However, despite advances in correction technologies, perfect compensation remains elusive, using conventional headphone designs, like Sennheiser HD 202 [7]. The complexity of nonlinearities, especially those introduced by headphone drivers and the coupling with the ear, means that the correction processes can only approximate ideal linearity, and residual errors may still affect the accuracy of the measurement [8].

In this paper, we examine the importance of maintaining a linear frequency response in audiology headphones, explore the inherent nonlinearities present in current headphone models, and evaluate the effectiveness of electronic correction systems in addressing these challenges. Understanding these factors is crucial for improving the precision of auditory measurements and ensuring that the results of audiometric testing are as reliable as possible [9].

MATERIAL AND METHODS

Development Directions

To achieve optimal performance in headphone design, several critical criteria must be met. An electrostatic transducer configuration is preferred, utilizing a membrane with uniform mass distribution and evenly applied tension to eliminate localized resonances caused by structural irregularities. The diaphragm should be sufficiently large relative to the earcup dimensions to support planar wave-front propagation. Additionally, the inner dimensions of the earpads should exceed those of the earcups themselves to prevent mechanical interference or deformation during use. This ensures both consistent acoustic coupling and effective isolation from ambient sound [10].

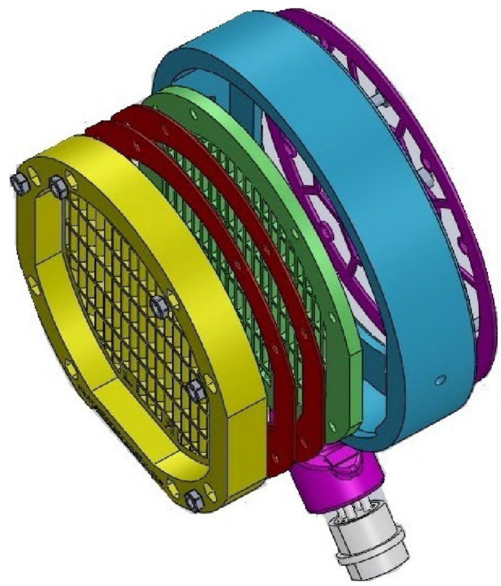

Fig. 6. *Self-Developed Electrostatic Headphone Construction*

Electrostatic transducers offer several key advantages: they facilitate planar wave propagation in both vertical and horizontal axes, exhibit directional (vectored) polar responses within the relevant frequency range, and produce a dipole radiation pattern that helps reduce lateral reflections. Moreover, they are characterized by a highly linear frequency response, minimal distortion, and fast transient response—properties essential for high-fidelity auditory measurements.

Reduced Reliance on DSP Through Improved Headphone Design

In audiological measurements, the accuracy and reliability of test results are heavily dependent on the linearity and consistency of the headphone's acoustic output. Conventional headphone designs often exhibit significant deviations from an ideal frequency response, particularly due to resonances, uneven driver behavior, and imperfect acoustic sealing. These imperfections necessitate complex digital signal processing (DSP) or software-based correction algorithms to compensate for transducer nonlinearities, spatial artifacts, and spectral coloration. While such corrections are essential, they introduce additional layers of signal manipulation that can never fully restore the original signal fidelity, and may even introduce phase errors or latency that affect measurement precision [10].

The implementation of high-performance headphone designs—such as electrostatic transducers with uniform membrane tension, large diaphragms for planar wave generation, and acoustically optimized earcup and earpad geometries—can significantly reduce these inherent acoustic distortions. Such designs naturally provide a flatter frequency response, more consistent polar patterns, and reduced harmonic and intermodulation distortion. As a result, the output signal more closely matches the input without the need for extensive DSP-based equalization or calibration [11].

This enhanced baseline performance reduces the computational burden on measurement systems and minimizes the dependency on correction filters. In practice, this means shorter calibration times, lower signal processing complexity, and fewer error sources in the measurement chain. Ultimately, the use of superior headphone construction contributes to more accurate threshold detection, better reproducibility of audiological tests, and a higher confidence in diagnostic outcomes—especially in clinical environments where precision is critical.

RESULTS AND DISCUSSION

As an initial step, the frequency response measurements are conducted using a semi-dummy head setup. A calibrated measurement condenser microphone is utilized in conjunction with the Audiomatica CLIO (2016) Electrical and Acoustical Measurement System. The procedure is carried out in two phases: first, measurements are taken without the earcup to establish a reference, followed by measurements with a simulated earcup in place to isolate and characterize the acoustic contribution of the earcup itself [12-14].

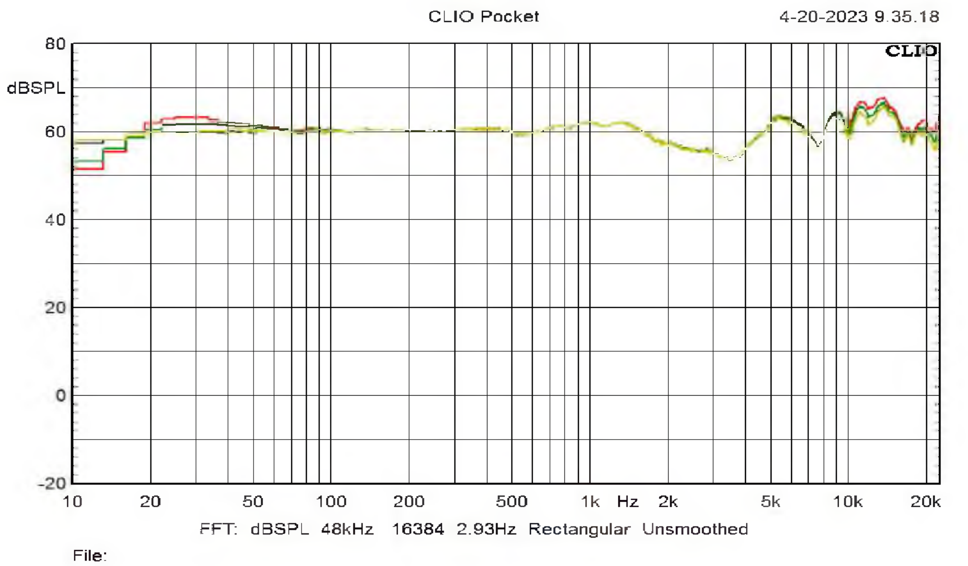

Fig. 7. *Frequency Response of the Self-Developed Electrostatic Headphones with Built-in Frequency Controls [14].*

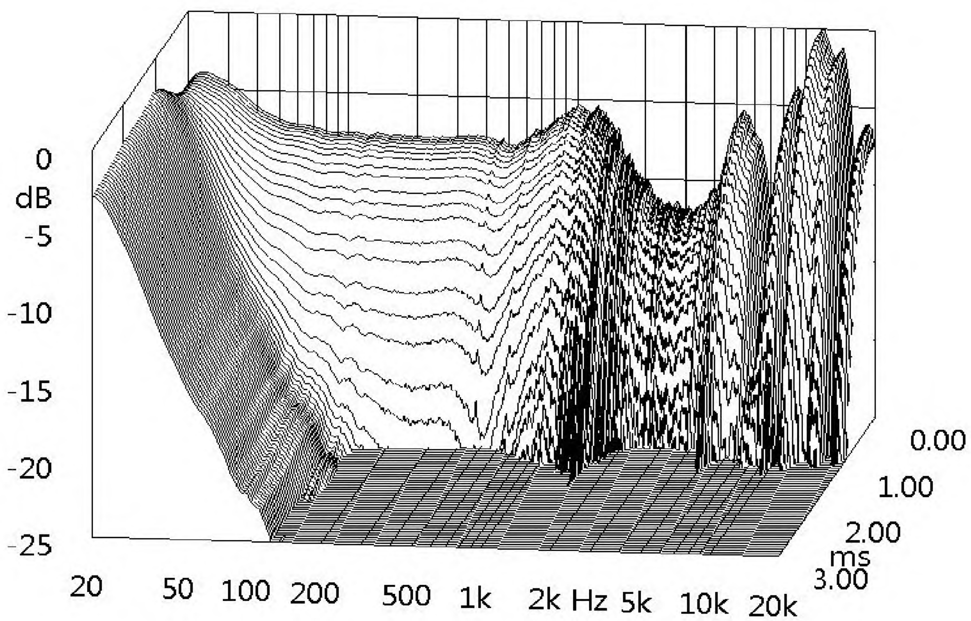

Fig. 8. *Waterfall Diagram of the Self-Developed Electrostatic Headphones [14].*

CONCLUSION

Accurate headphone performance is essential for high-precision audiological measurements, where even minor deviations in frequency response can compromise diagnostic reliability. While traditional headphone designs often require complex digital correction to compensate for acoustic nonlinearities, these corrections are inherently limited and cannot fully restore a linear, phase-coherent response.

This study highlights how advanced headphone construction—particularly electrostatic designs with large, uniform membranes and optimized acoustic coupling—can inherently reduce frequency response irregularities. By minimizing the need for extensive DSP-based compensation, such designs improve measurement accuracy, reduce computational overhead, and enhance repeatability in clinical and research settings.

Ultimately, investing in transducer technologies that prioritize physical linearity over post-processing correction leads to a more robust, reliable foundation for audiological testing, paving the way for improved diagnostic tools and more trustworthy auditory assessments.

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