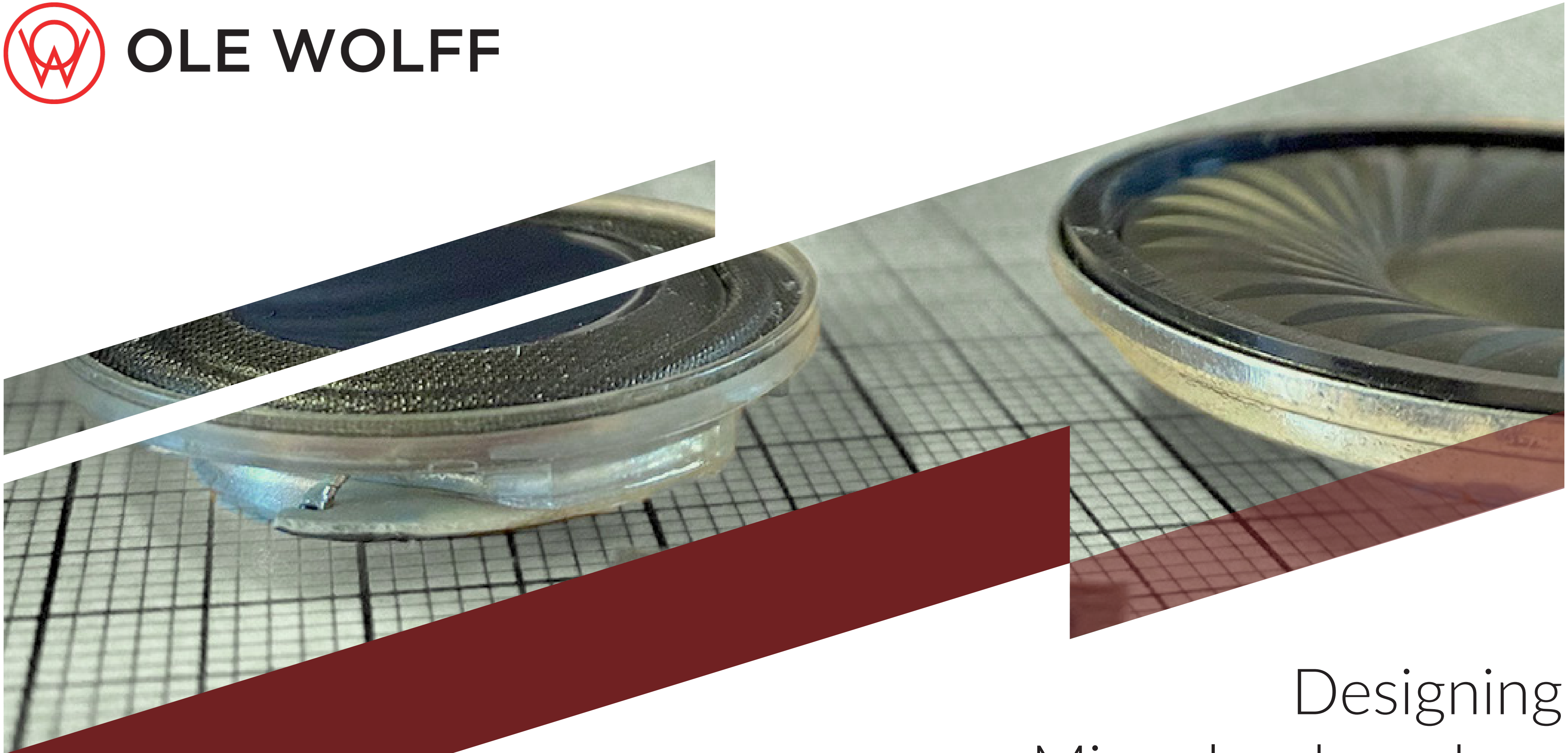
OLE WOLFF



Designing Micro loudspeakers for Portable Devices

Part II - Nonlinear performance

WP04

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Introduction

Nonlinear performance parameters are present as well in loudspeaker design, and they are crucial because they are undesirable and directly impact sound reproduction quality. The parameters here are distortion (THD), intermodulation distortion (IMD) and Rub&Buzz (R&B).

These parameters, are as mentioned, related to all nonlinear behavior in the design, meaning the structures in the loudspeaker which are not ideal. In mechanical assemblies, especially when miniaturized, significant tolerances exist both in the individual piece parts and in the assembly processes. Assembly fixtures also contribute to the overall tolerance chain.

Nonlinearities directly related to the specific design also exist and can for example be caused by improper engineering design of the membrane related to stress of the materials under full membrane displacement, where the membrane is forced to “break up” into different modes because the suspension was not designed to handle the maximum stroke needed at highest sound pressure levels.

We can make a distinction between THD/IMD, and R&B as follows:

In popular terms, Total Harmonic Distortion (THD) and Intermodulation Distortion (IMD) are associated with unwanted sound pressure signals that increase “linearly” as electrical voltage increases. On the other hand, Rub and Buzz (R&B) is linked to unwanted sound pressure signals that start abruptly at a certain voltage signal and then rapidly escalate in level with even a slight increase in electrical voltage.
THD typically affects sound quality to some extent, but it’s usually less severe as it tends to occur at lower frequencies.
IMD affects sound quality in a degree higher than THD, because IMD harmonics are located around the intermodulation frequencies, which are distributed up into the passband, where the human ear is medium sensitive.
In contrast, R&B happens at middle to high frequencies, where the human ear is highly sensitive, resulting in it being perceived as extremely annoying and indicative of poor sound quality.

General design principles

The following section deals with design principles on how to optimize the linear performance, suppress the unwanted nonlinear performance of the loudspeaker related to the design as well as design principles related to the reliability of the loudspeaker.

Coil diameter

To achieve the optimal cooling effect, it is recommended to design the coil with the largest possible diameter, as this will maximize the surface area compared to a smaller diameter coil design.

At power levels of 2W (the current standard for the highest steady-state power handling in micro-loudspeakers for portable devices), the coil temperature will reach approximately 110°C. Therefore, it is essential to use coil wire designed for high temperature and high power performance.

Air gap in magnet system

A narrower air gap in the magnet system increases sensitivity. However, due to tolerance issues in mass production, it is not recommended to reduce the nominal gap to less than 0.15mm on either side of the coil in free air.

Moving mass

The lower the moving mass, the higher the acoustic sensitivity above the resonance frequency (F0) of the loudspeaker. The moving mass consists of the mass of the coil, the piston plate, and the glue between the piston plate, coil, and suspension. Therefore, materials for the membrane (piston plate) should be as light and stiff as possible.

Using CCA (Copper Clad Aluminum) wire can significantly reduce the moving mass. However, to maintain a low required resonance frequency, a very soft suspension is needed. This can be achieved either by using a very thin foil for the suspension/membrane or by using molded silicone for the suspension.

Wire manipulation

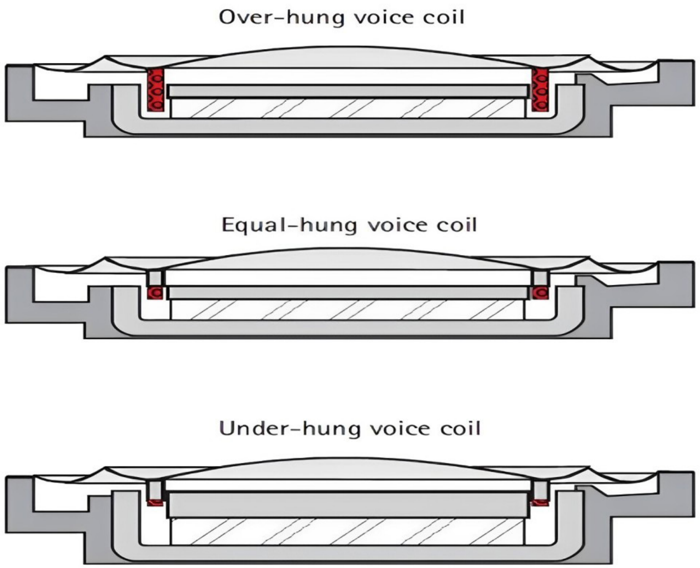
Modern micro loudspeakers have a maximum membrane displacement of approximately ±0.4mm at or below the resonance frequency. Given the overall thickness of the loudspeaker, which ranges from 2.5mm to 3.5mm, this displacement is substantial and poses a significant challenge in maintaining the balance of the moving mass. The wire manipulation is particularly critical, as it must accommodate full movements at the coil side while remaining stationary at the terminal side. Using “white oil” types can usually help mitigate Rub & Buzz issues by stabilizing the wires.

To address these challenges, it is recommended to incorporate 3D simulation of the wire manipulation wherever possible.

Motor

In micro loudspeakers, it is generally standard practice to design for an overhung coil in relation to the air gap to achieve the most linear performance and reduce distortion.
In an overhung design, the coil is taller than the magnetic gap, assuring approximately the same number of windings in the active field even at highest membrane excursions *(see fig. 1)*. In other words, when some windings are leaving the field at one end, other windings are entering the field at the other end and thereby the full sensitivity is maintained even at the highest sound pressure levels. The name of this performance parameter is known as low compression.
The trade off when designing an overhung coil is, that the moving mass increases and thereby the sensitivity will be relatively lower compared to an equal- and under-hung voice coil.

Fig. 1



Venting holes

To achieve the highest sensitivity, it is recommended to design for maximum venting from the rear side of the membrane to the back cavity. While using a dust shield to cover this rear venting can positively affect distortion and Rub & Buzz, it will result in slightly reduced sensitivity and added cost.

The rear venting should be as symmetrical as possible (relative to the center of gravity of the speaker) in order to have the most homogeneous load of the membrane and thereby the lowest distortion & Rub&Buzz performance.

Front cover/grill

The main purpose of the front cover/grill is to protect the membrane and provide a surface for an adhesive gasket. Acoustic recommendations for the front cover design are similar to those for the venting holes: it should be as open as possible to achieve the highest sensitivity. However, a dust shield covering the opening in the front cover can improve Rub & Buzz and Total Harmonic Distortion (THD) performance by adding damping, but it comes at the cost of slightly reduced sensitivity and increased expense.

Membrane material

Thermoformed foil is the most commonly used material for membranes in micro speakers. PC foil was widely used in the past, but its commercial sales were halted some years ago due to its potential use in the manufacture of explosives. As a substitute, a foil called PAR was developed by a tech film manufacturer and is now one of the most commonly used foils, together with PEEK, PET, and PEN foils, for micro loudspeaker membranes.

To achieve the most linear performance of the membrane, it is recommended to use laminated foils. This introduces some mechanical friction loss to the suspension, particularly at the outer edge of the membrane, which aids in reducing nonlinear behavior. A PEEK/PUR/PEEK sandwich foil, where PUR is the adhesive part keeping the layers together, is typically a good choice for this purpose. More recently, 5-layer laminates have been available in the market, further enhancing the mechanical loss element in the suspension.

Conclusion

These whitepapers (WP03 and WP04) should be viewed primarily as a guideline for understanding the fundamentals of designing micro loudspeakers, rather than a comprehensive "cookbook."

However, when combined with strong general engineering skills, material and process knowledge, common sense, and ample practice, it provides valuable insights into the tools used at Ole Wolff to expedite the development process of new and innovative micro loudspeakers and receivers.

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