Identifying unsound resonances of smartphone loudspeakers

SmarAct | metrology

INTRODUCTION

The advent of mobile communication has been pushing the miniaturization of loudspeakers, devices that convert electrical signals into audible pressure waves by the actuation of a movable diaphragm. The challenge consists of maintaining a good sound quality, which strongly depends on the design, choice of materials and manufacturing tolerances, while reducing the dimensions.
On one hand, experimental measurement tools are required to help designing the devices. Traditionally the sound pressure *vs.* frequency is recorded with a reference microphone. However, while this method allows to analyze the device performance and eventual spectral distortions it lacks the ability to trace back their origins.
On the other hand, computational approaches such as finite element analysis are used to predict vibrational modes of the several parts of the loudspeaker assembly and thus their influence on the loudspeaker performance. Nevertheless, the effects of production tolerances and mounting stresses are difficult to include.
In a nutshell, the actual measurement of vibrations remains essential to characterize the performance of loudspeakers and will help to further improve their design.
Here, we employed SmarAct's **PICO**SCALE *Vibrometer* to directly measure and visualize vibrational modes of the diaphragms and housings of two different smartphone loudspeakers. The results show clear correlations between the measured spectral irregularities and the mechanical resonances of different components of the devices.

METHODS

The experiments were performed on a standard **PICO**SCALE *Vibrometer*. The loudspeakers were removed from smartphones from two different manufacturers and are referred to as "Loudspeaker 1" and "Loudspeaker 2". Both loudspeakers were mounted with a small amount of glue on a 30 g aluminum block. The loudspeaker coil was connected directly to the output of the shaker-stage amplifier which outputs the reference signal for the lock-in amplifier. A 10 µF capacitor was placed in one of the lines to remove the DC component of the signal. The experimental workflow was as follows:

1. Record a microscopy image of the whole loudspeaker at 200 $\times$ 200 pixels.
2. Position the measurement laser onto the diaphragm and use the autofocus option to focus the laser.
3. Drive the loudspeaker with a linear sweep at constant amplitude from 0.5-16 kHz using the function generator of the **PICO**SCALE *Vibrometer*. The measured displacements are Fourier transformed to show the amplitude in the frequency domain.
4. Select a peak in the amplitude spectrum and actuate the loudspeaker at this frequency.
5. Scan the loudspeaker at 1 Megapixel resolution. Simultaneously with the microscopy image now also the amplitude and phase of the oscillations were recorded at each pixel by the digital dual-phase lock-in amplifier. The latter is automatically configured according to the actuating frequency.
6. Refocus the measurement laser onto the loudspeaker housing and repeat the 1 Megapixel scan while actuating the loudspeaker at the same frequency.
7. Reconstruct the deflection of the sample at each point of the oscillation cycle by using the standard **PICO**SCALE *Vibrometer* VIEW software. Basically, for each pixel the deflection, d, is calculated from the measured amplitude, A, and phase θ according to $d = A \cdot \cos(\theta)$.

RESULTS

Loudspeaker 1: Loudspeaker 1 has an unprotected transparent rectangular diaphragm. Figure 1a shows the microscopy reflection image at 1 Megapixel resolution. Because the transparent diaphragm sits only a fraction of a millimeter above the loudspeaker's magnet the autofocus routine will detect two foci. For this experiment the upper focus, corresponding to the diaphragm was selected. After focusing, the confocal measurement principle of the **PICO**SCALE *Vibrometer* ensures that only light that is reflected from this focal volume is detected while all light that reflects from out-of-focus objects, such as the magnet, is suppressed. The diaphragm is clearly defined in the reflection image even if it appears transparent at visible light. The local vibrations (marked by the green dot on the reflection image) from 0.5 kHz to 16 kHz are displayed in Figure 1b. Interestingly, two resonance peaks at 7.5 kHz and 12 kHz were detected. To reveal the origin of these peaks the loudspeaker was actuated accordingly which resulted in the deflection images shown in the insets of Figure 1b. The 7.5 kHz resonance hits the second bending mode of the diaphragm as one circular nodal line is visible: the periphery of the diaphragm (in light blue) moves in the opposite direction as the central part (in red). At 12 kHz a more complex vibrational mode is visible: the long edges of the diaphragm oscillate in phase with the central part (both in red). At both frequencies the motion of the metal housing was minimal.

Loudspeaker 2: Loudspeaker 2 has a metallic diaphragm that is protected by a metal cover. The latter contains rectangular apertures (6 of 2.5x1.25 mm and 3 of 4x1.25 mm) through which the diaphragm, lying approximately 0.5 mm underneath, can be seen. Figure 2a shows the microscopy re-

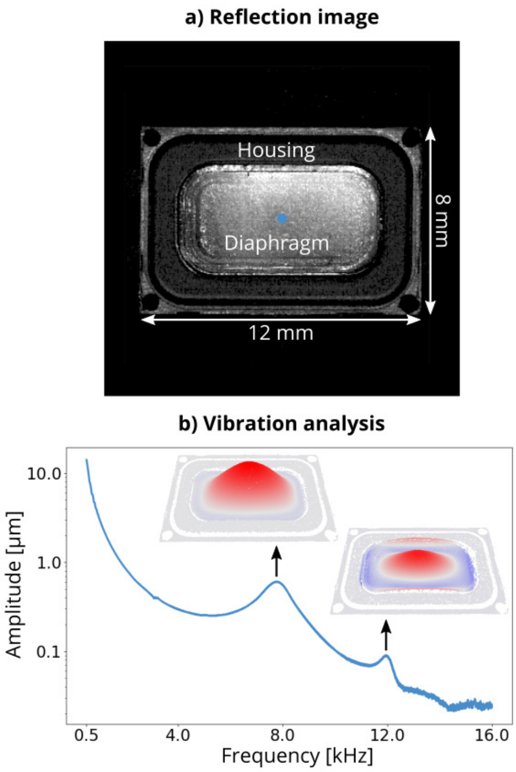

Figure 1. Investigation of Loudspeaker 1. ***a**) The reflection image displays the unprotected diaphragm surrounded by its metal housing.* ***a**) Local measurement of the amplitude spectrum at the blue dot in the reflection image shows two resonant peaks at 7.5 kHz and 12 kHz. Insets: Deflection images of the vibrational modes at these respective excitation frequencies.*

flection image of the complete loudspeaker at 1 Megapixel resolution. The metal cover is highly reflective while the diaphragm, seen through the apertures, is less clearly defined. Nonetheless, after refocusing on the diaphragm the signal quality was sufficient to measure the local vibrations (marked by the green dot on the reflection image) from 0.5 kHz to 16 kHz, see Figure 2b. Similarly to Loudspeaker 1, two frequency components at 6 kHz and 11.5 kHz stand out in the amplitude spectrum. Imaging the vibrational modes at these frequencies reveals that the 6 kHz component hits the first bending mode of the metal cover which in turn weakly excites the diaphragm. On the other hand, exciting the device at 11.5 kHz appears to actuate the diaphragm at its second bending mode (the periphery of the diaphragm (in light blue) moves in the opposite direction as the central part (in red)) while the cover is hardly moving.

CONCLUSION

SmarAct's **PICO**SCALE *Vibrometer* was used to characterize the dynamic performance of two smartphone loudspeakers. By imaging at different focal planes both the response of the diaphragm and the housing could be analyzed. Although each loudspeaker showed two pronounced peaks in the amplitude spectrum, the underlying phenomena are different. In Loudspeaker 1 the resonances are explained by vibrational modes of the diaphragm whereas in Loudspeaker 2 one of the resonance peaks is caused by the excitation of the metal cover. Understanding such correlations between

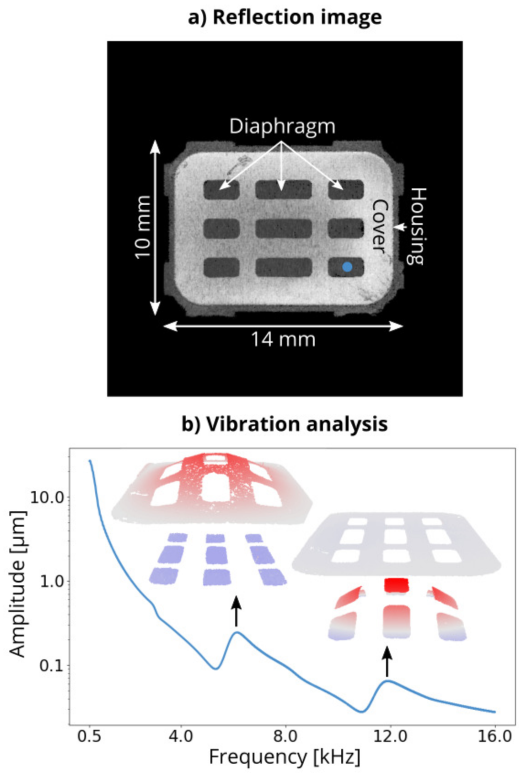

Figure 2. Investigation of Loudspeaker 2. ***a**) The reflection image displays the diaphragm through the apertures of the highly reflective metal cover.* ***b**) Local measurement of the vibrations at the blue dot in the reflection image shows two resonant peaks at 6 kHz and 11.5 kHz. Insets: Deflection images of the vibrational modes at these respective excitation frequencies.*

amplitude spectra and vibrational modes will help to further optimize the design of electroacoustic transducers.

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