

Characterization of dynamic loudspeakers using electrical and acoustical measurement data

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Introduction

Electrodynamic loudspeakers can be characterized by a set of Thiele-Small parameters [1] (Fig.1) when operated in the low-signal linear regime. The measurement of these parameters allows the prediction of the membrane velocity and sound pressure for arbitrary input signals. It is investigated whether a sound pressure measurement in the speaker's far field is suited for speaker characterization and how it performs compared to surface velocity measurements using a laser vibrometer, regarding the accuracy and reproducibility of the results.

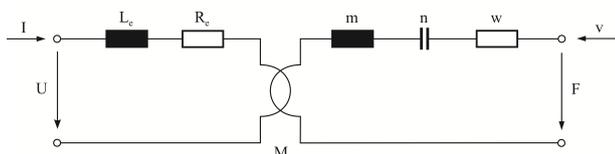


Figure 1: Electro-mechanical model of a dynamic loudspeaker. [2]

Modeling of Sound Radiation

For on-axis measurements in the far field of a piston radiator with the membrane area S_d , the sound pressure at a distance r can be related to the membrane velocity v .

$$p(\omega, r) = j\omega\rho \cdot \frac{e^{jkr}}{2\pi r} \cdot S_d \cdot v(\omega) \quad (1)$$

Here, k refers to the wave number, ω is the angular frequency and ρ is the mass density of air. Figure 2 shows the RMS sound pressure measured at various distances in front of a small loudspeaker. Each measurement was repeated ten times without repositioning of the speaker.

Least-square error fits were performed to fit the mean pressure values, respectively weighted with their inverse standard deviation, to a function of the form

$$p_{RMS}(r) = \frac{a}{r - b}. \quad (2)$$

This function describes the general far-field behaviour, allowing a difference in the membrane position and the acoustic center of the speaker [3]. Outliers in the near field were excluded from the fit until the data showed a reasonable agreement with the theoretical prediction.

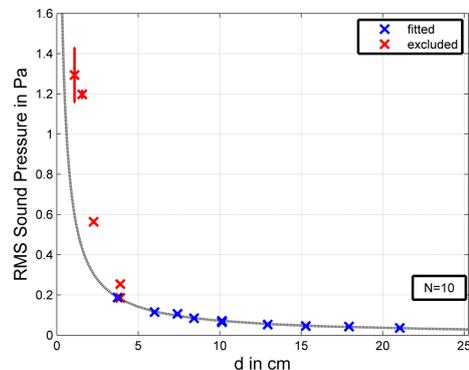


Figure 2: Measured on-axis RMS sound pressure over the distance from the source. A shifted $1/r$ - law is fitted to the data in order to determine the far-field regime.

Measurement and Analysis

Transfer function measurements were conducted separately with a laser vibrometer (velocity) and a small electret microphone (pressure) as shown in Figure 3. In addition to both, the electrical impedance was measured at the device terminals.

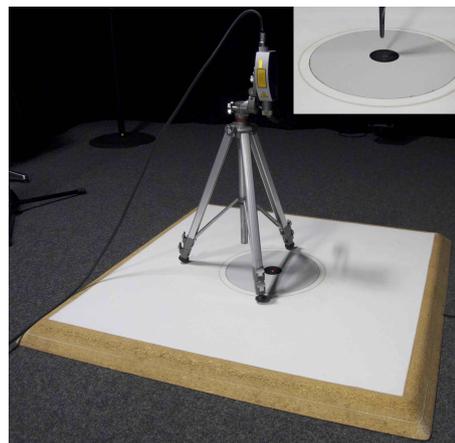


Figure 3: Measurement setup for velocity measurement using a laser vibrometer (large) and for sound pressure measurement using a microphone (top right).

Measurements were conducted with a broad band sweep-signal excitation [4] while the speaker was mounted in a baffle in order to avoid edge diffraction effects. The results were fitted to the respective model functions (cf. Fig. 4) using a least-square fitting algorithm. For the acoustical measurement, only a limited frequency band could be used, because room reflections (low frequencies)

as well as surface modes on the membrane and edge diffraction (high frequencies) caused considerable deviation from the model. The phase change in the pressure signal due to propagation was compensated analytically before the fit was conducted. Also, the distance between microphone and loudspeaker was obtained from the impulse response of the acoustical measurement, i.e. the run-time of the sound signal.

The laser measurement as well as the acoustical measurements for each distance were repeated ten times and the fitting was done for single measurements, without averaging. The goal of this procedure was to investigate reproducibility.

All measurements and the analysis were conducted using the ITA-Toolbox [5].

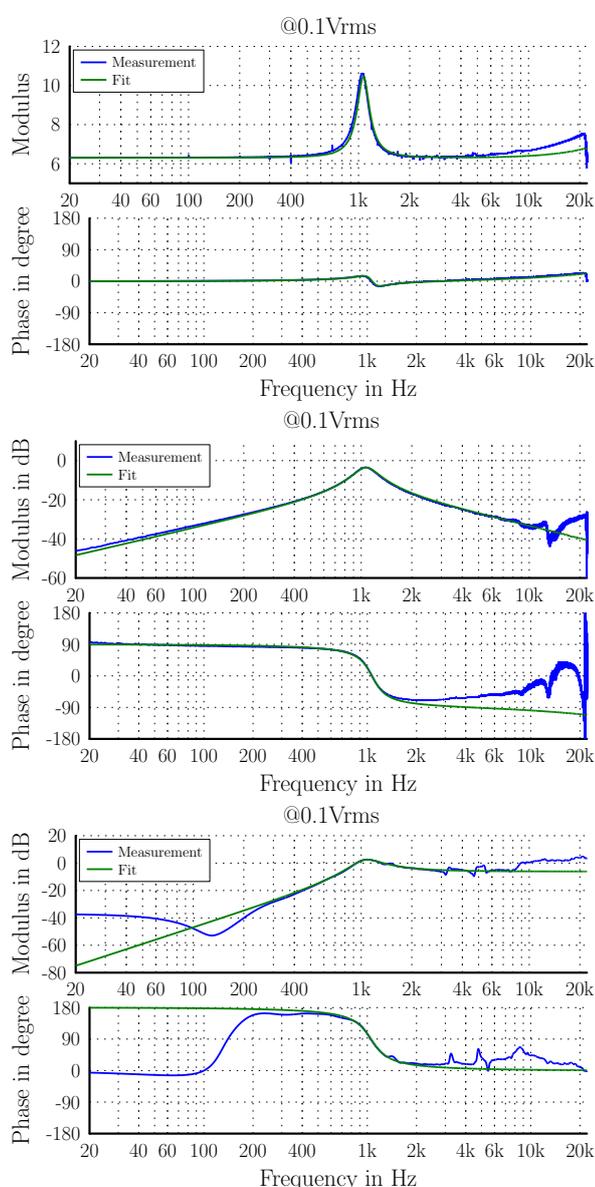


Figure 4: Measurement and Fit Results (a) Electrical Impedance, fitting range 20 .. 10.000 Hz (b) Membrane Velocity, fitting range 20 .. 10.000 Hz (c) Sound Pressure, fitting range 500 .. 2.000 Hz

Results and Discussion

The resulting Thiele-Small parameters are shown in Figure 5 for both methods.

The reproducibility of characterization parameters is much higher for the laser measurement, as can be seen in Figure 5. Also, the reproducibility of the acoustic measurement increases for larger distances between microphone and speaker. This is an indication that the actual far field approximation assumed by the fitting algorithm becomes increasingly accurate. However, the deviation to the results from the laser measurement also increases for larger distances.

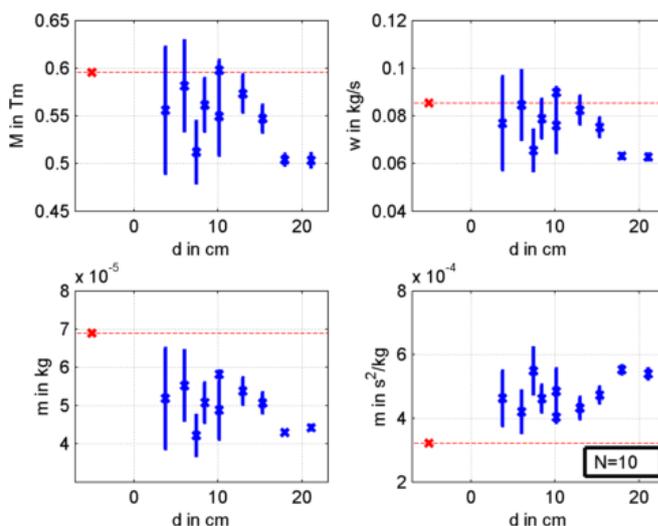


Figure 5: Thiele-Small Parameters (Mean values and standard deviation) fitted from laser measurement (red) and acoustical measurement for various distances (blue)..

Figure 6 compares the measured sound pressure in 50 cm distance to the speaker to the predictions from both characterization methods, i.e. the laser measurement and the acoustical measurement, both combined with a measurement of the electrical impedance, respectively.

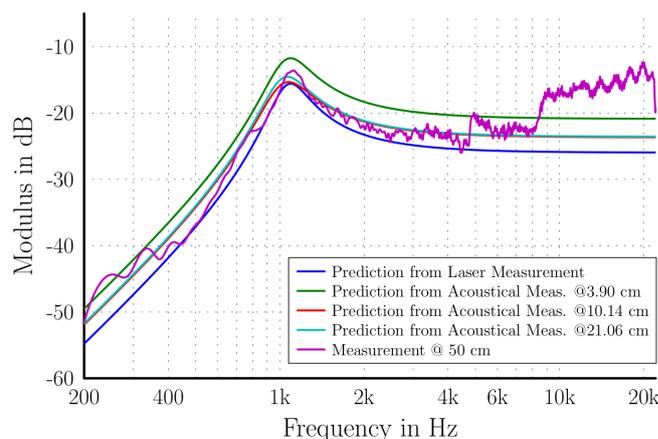


Figure 6: Measured sound pressure at $d = 50$ cm from the speaker and the respective predictions from Thiele-Small parameters obtained from laser measurement and acoustical measurements at various distances.

For small distances, the acoustical measurement does not predict the measured far-field sound pressure. This can be explained with the information shown in Figure 2, i.e. the deviation from the used far-field radiation model for measurements in the near field. However, also acoustic measurements at farther distances show different results than those conducted with a laser. A possible explanation is the insufficient accuracy in the approximation made in the modeling function for the far field sound pressure.

Conclusion and Outlook

The results show that reproducible loudspeaker characterization is possible from only electrical and acoustical measurement data. A certain minimum distance has to be kept between speaker and microphone, so that the far-field approximation is valid. However, the results show a systematic deviation between acoustical and optical measurement which should be investigated further. Also, an investigation for different loudspeaker models should be done and compared to the results presented here. A next step will be the gradual simplification of the setup in order to reduce the measurement effort, while still permitting a sufficient accuracy of the used mathematical model. The final target is a simple acoustical measurement which produces results that are consistent with those from a laser vibrometer.

References

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