Flowmeter and audio application of wideband ultrasonic transducer

Jürgen Peissig, Vladimir Gorelik and Rainer Wiggers

Sennheiser electronic GmbH & Co.KG, Am Labor 1, 30900 Wedemark, Germany,
Email: peissigj@sennheiser.com

Introduction

Well known applications for ultrasonic (US) transducers are movement- and distance measurement applications as well as flow meter applications like anemometers and spirometers. All applications demand high transducer quality in terms of short impulse response and insensitivity to environmental influences. These applications work at moderate sound pressure levels (SPL). A special application is the US parametric transducer [1] which, on the contrast demands very high US output level and a high transducer directivity only in a narrow frequency band. Having a short impulse response together with high SPL are two conflicting demands when it comes to optimise a real transducer system.

Starting from earlier experience with the manufacturing of US transducers for TV remote controls we developed new highly efficient US transducers for both applications. The transducers are built according to the electrostatic 'Sell' principle and can be delivered as small capsules and as large plane high-power transducer with very high directivity.

The capsules are intended to be used in flow-meter applications whereas the large transducers where tested to deliver extremely high outputs for a parametric transducer - the Sennheiser AudioBeam.

Transducer theory

The sound pressure p generated by a membrane with the surface area A and the velocity v can be written as:

$$p = \rho c v (ka^2 / 2r) = \frac{\rho \omega v A}{2\pi r} \qquad (1)$$

were r denotes the distance from the membrane and ω the angular frequency.

The velocity of the membrane in the electro-mechanical system driven by the Coulomb forces $F_C = Fe^{i\omega t}$ can be described by:

$$v = \frac{F_C}{i\omega m + \frac{1}{i\omega C} + R} = \frac{F_C}{Z_{mech}} \qquad (2)$$

with m: mass, C: compliance and R: resistance of the mechanical system.

Inserting equation 2 into 1 and demanding a flat frequency response the system has to be operated in the frequency range were the mass-impedance term ($Z_{mass} = i\omega m$) dominates Z_{mech}. This holds for frequencies ω above the resonance frequency were $\omega \cdot m >> 1/\omega \cdot C$. At the resonance frequency $\omega \cdot m = 1/\omega \cdot C$ the system is damped by resistance and shows an increasing slope of 6dB/oct. Below resonance frequency $\omega \cdot m << 1/\omega \cdot C$ we see a 12dB/oct increasing slope. As a result the transducer membrane has to be fastened with large compliance because of its small mass.

Construction

To obtain high Coulomb forces the air gap between membrane and back-electrode has to be as small as possible. To avoid the membrane to stick on the back-electrode when polarisation voltage is applied, Sell proposed supporting structures on the electrode [2] which can be constructed in various ways [3]. During construction of the transducer we aimed at two goals: a) minimum loss at the vibrating membrane caused by the supporting structures and b) maximum drive due to the electric field in the gap. This was achieved by a back-plate construction described in [4].

Acoustical measurements

Figure 1 shows a picture of the miniature US transducer capsule with a diameter of 14.5 mm and a height of 4.7 mm.

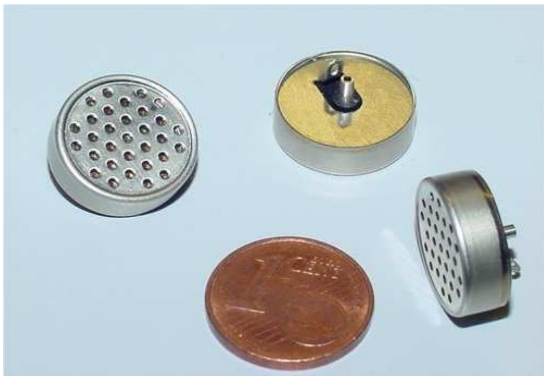

Figure 1: Miniature US transducers with 1 euro cent.

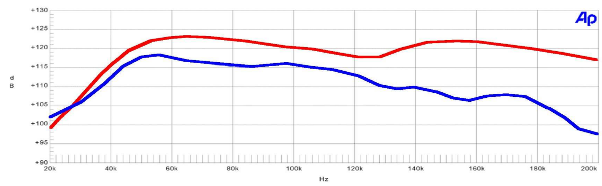

Figure 2: SPL of the US miniature capsule from 20kHz to 200kHz. Red line: without frontal baffle: increased SPL of 20dB at 200kHz. Maximum SPL 124dB.

The SPL measurements in Figure 2 where taken with a B&K measurement microphone 4138 without the protecting input baffle. Measurements where taken in a distance of 10 cm with a polarization voltage of 200V and a 120Vpp signal voltage.

The directivity of the US transmitter was measured in an anechoic room. The capsule was placed on a turntable and the receiving microphone (B&K 4138) with dismounted input baffle was used. The resulting directivity curves are shown in Figure 3.

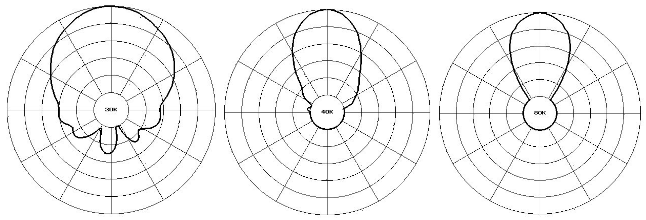

Figure 3: Directivity plots of the miniature capsule. left: 20kHz, center 40kHz, right: 80kHz. 0° incidence is set to 0dB. 5dB attenuation per division. 25dB max attenuation visible on the plots.

The newly developed imprinting technology allows to have very precise and optimal structuring of the counter electrode not only for small transducers but also for large scale high-power transducers and also non-plane transducers. The maximum transducer size we have assembled so far is 182 x 289 mm (approx. DIN A4). The transducer is shown in Figure 4.

Figure 4: High-power ultrasonic transducer (size: DINA4)

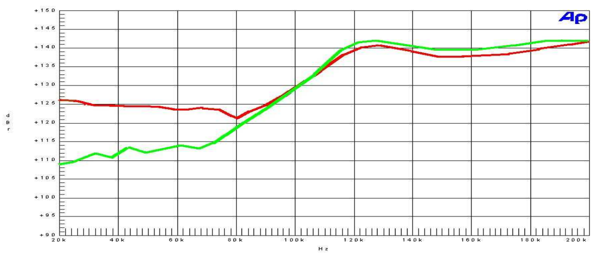

Figure 5: Frequency response of the high-power US transducer from 20kHz to 200kHz with 20kHz/div. The maximum SPL was 142dB (red and green line differ in the membrane tension) with 5dB SPL/div. Measurements were taken in a distance of 1m.

With non-plane transducer structures (e.g. cylindrical) it should be possible to generate a broad directivity pattern although the membrane surface is large.

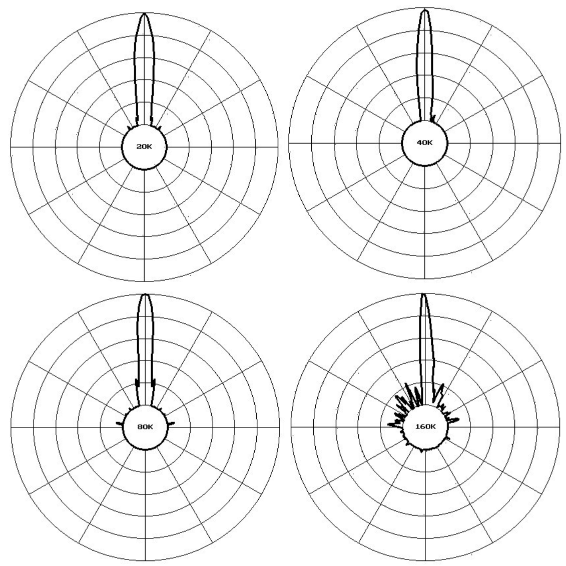

Figure 3: Directivity patterns of the high-power US transducer with the size of 183x292mm. From left to right: 20kHz, 40kHz, lower row: 80kHz, 160kHz measurement frequency. Maximum SPL at 0° was normalised to 0dB in each plot. The attenuation per division is 5dB resulting in 25dB maximum attenuation shown in the plot.

The Transducer thickness is 6mm. The transducer is operated at 200V polarisation voltage with a maximum of 75Vpp signal voltage. The capacity is 25nF without polarisation voltage.

Conclusion

A new imprinting on the counter electrode of US condenser transducers allows the assembly of very efficient capsules and large membrane surface transducers. The small capsules can be optimised for linear frequency response from 20kHz up to 200kHz at 125dB of SPL. The high power transducer offer up to 142dB of US pressure level at 120kHz. The counter electrode suspension structure allows curved, non-plane transducer surface (e.g. in cylindrical shape). Such a setup would have a toroid-like directivity. Not only convex but also concave structures can be designed, because the polarization voltage pulls the membrane to the back-electrode.

Both the small capsules and the plane transducer can be operated as speakers and microphones and form a complementary pair of broad band US transducers opening a large amount of new applications.

[1] Neue Möglichkeit der Schallwiedergabe. *rfe* 1-2/00

[2] H. Sell, Eine neue kapazitive Methode zur Umwandlung mechanischer Schwingungen in elektrische und umgekehrt. Zeitschr. f. techn. Physik, Nr.**1**(1937), 3-10

[3] L. Pizarro, D. Certon, M. Lethiecq, O. Boumatar, B. Hosten, Experimental Investigation of Electrostatic Ultrasonic Transducers with Grooved Backplates. 1997 IEEE ULTRASONIC SYMPOSIUM – 1003

[4] V. Gorelik, Hocheffektive breitbandige Ultraschall-strahler, Fortschritte der Akustik, DAGA 2003.