Holographic Measurement of Electroacoustic Transducers in a Baffle

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Introduction

To measure electroacoustic transducers under standardized conditions of the half space measurement, the device is usually mounted in floor in a half space anechoic room, which avoids the acoustical shortcut between front and backward sound and the transducer can be measured without the influence of an enclosure.

But usually the measurements are performed in full anechoic room and the transducers are mounted in a normalized baffle. Due to limitation of the baffle size, diffraction effects from the edges cause ripples in the frequency response, and the acoustical shortcut for low frequencies can also limit the measurement range. The measurement provides no 3D directivity since the baffle can not be rotated. But this 3D sound data is required for analyzing and improving sound radiation characteristics of audio devices.

Furthermore, no anechoic room is perfect. It provides always insufficient damping at lower frequencies (<100 Hz), which makes the measured frequency response in lower frequency range very inaccurate. Concerning the dimension of a large transducer, a large measurement distance may be required. To ensure accurate phase information, especially for high frequencies, the climate conditions along sound propagation should be controlled, since the temperature of the air affects the speed of the sound. For example, a temperature increase by 2 Kelvin will cause a speed difference of 1.2 m/s and already generate a phase error of 36º (0.1 λ) at 10 kHz over a 2 m distance.

Near Field Measurement

The near field measurement can date back to 70's of last century. Comparing to the far field measurement, it has several advantages. First of all, it provides a high signal-to-noise ratio, because the microphone is very close to the sound source. Therefore, the transducer can be measured faster without time averaging. Second, the Amplitude of direct sound are much greater than room reflections, which ensures a simulated free field condition for high frequencies by using windowing techniques. Third, due to the short measurement distance the influence from air properties can be negligible.

However, in the near field the sound source radiates no plane wave. The velocity and sound pressure are out of phase. Hence, the 1/r-law can't be applied to extrapolate the sound pressure into the far field. A solution is the holographic approach. The measured sound pattern in the near field can be approximated by using a model, and with this model the extrapolation of the sound pressure at any point in the far or near field is valid.

Holographic Method

The holographic wave expansion uses special spherical solutions of the Helmholtz equation: Hankel functions and spherical harmonics as basic functions. According to [1], the complex sound pressure p between the measurement surface and other external boundaries (e.g. room walls) can be decomposed into two pressure parts depending on the wave radiating directions: p_{out} (outgoing wave) and p_{in} (incoming wave), and each part can be described with a multi-sum of basic functions and corresponding weighting coefficients $C_{n,m}$.

$$p(r,\phi,\theta,\omega) = p_{out}(r,\phi,\theta,\omega) + p_{in}(r,\phi,\theta,\omega) \tag{1}$$

$$p_{out} = \sum_{n=0}^{N} \sum_{m=-n}^{n} C_{n,m}^{out}(\omega) \cdot h_n^{(2)}(kr) \cdot Y_n^m(\phi,\theta) \tag{2}$$

$$p_{in} = \sum_{n=0}^{N} \sum_{m=-n}^{n} C_{n,m}^{in}(\omega) \cdot h_n^{(1)}(kr) \cdot Y_n^m(\phi,\theta) \tag{3}$$

In this model, the Hankel functions of the first kind $h_n^{(1)}$ and second kind $h_n^{(2)}$ describe the radial wave radiation from near into far field and use different phase shifts to define the radiating directions. The spherical harmonics Y_n^m characterize the angular dependency over the spherical angles phi and theta. As shown in figure 1, they are elementary spherical wave radiators and orthogonal to each other.

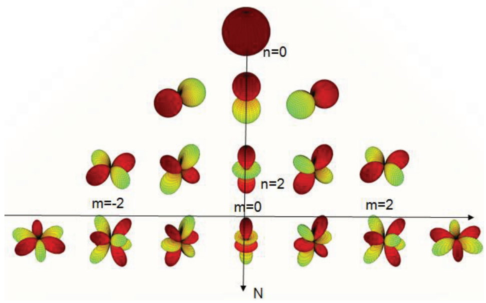

Figure 1: Spherical harmonics Y_n^m (real parts)

The expansion coefficients can be determined by matching the model to the measured acoustic pressure. The generated fitting error [2] can determine the accuracy of the results and optimize the expansion order N, which directly related to the number of measurement points and measurement time. A fitting error which is smaller than 1% can practically assure a good matching [3].

After determining the coefficients at the measurement surfaces, the characters of the sound source can be described by the coefficients. Its radiated sound field can be extrapolated into free field to any point outside the scanning surfaces and the corresponding 3D directivity can also be calculated.

Scanning Process

To identify the sound wave directions with the expansion model, two spherical measurement surfaces around the DUT are required [4] and they should be close to each other. But if the DUT is a transducer with a baffle, a 2π-scanning on two hemispherical surfaces in front of the baffle should be performed. One of the benefits is killing the acoustical shortcut at lower frequencies and diffractions from the edges of the baffle, because those effects are outside the scanning surfaces and can be separated by sound separation. Thus the 2π-scan provides a perfect half space measurement. The transducer now can be measured in smaller baffles (see figure 2). But the baffle must be larger than the scanning surfaces.

Figure 2: Klippel Near Field Scanner

To acquire the spherical data on two hemispherical surfaces, the Klippel Near Field Scanner is used. It is an automatic measurement system controlled by the scanning software. As shown in figure 2, the small baffle can be positioned in the center of the scanner. During the scanning, the microphone rather than the baffle or other DUTs is moved to each defined measurement point, because the small microphone can be positioned more accurately than DUTs. Furthermore, the non-moving sound source ensures a constant room response, which makes field separation techniques and non-anechoic measurement possible.

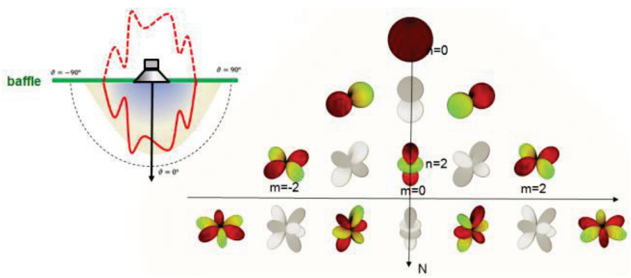

Figure 3: Spherical harmonics used for a baffle symmetry

In addition, the sound wave reflected on the baffle can be modeled by a mirror sound source. Then the total sound field is axis symmetrical to the baffle surface. To match the measured pressures with the wave expansion, the symmetry properties of the basic functions must be taken into account. As shown in figure 3, we only use the sets that are symmetrical to the axis ϑ = 90º. By this means, the total number of required coefficients is reduced by almost 50%, which also decreases the total scanning time.

Measurement Results

As seen in figure 4, there are two techniques applied to separate the sound field. For frequencies above 1.5 kHz, it is realized by using time windowing upon the measured impulse responses. As a result, the direct sound (blue) is in accordance with the measured sound data (green). At lower frequencies, the sound field must be separated by holographic processing. The room reflections (red) can be characterized as incoming waves. They can be identified by the model and removed from the total measured sound part. Thus the direct sound field can be separated successfully. After that other data, such as sound power, sensitivity, 3D directivity and so on, can be determined at selected frequency and position.

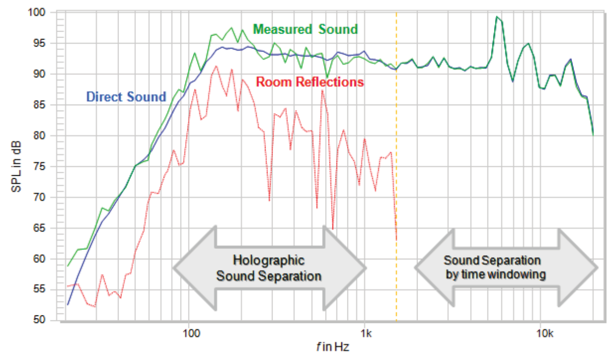

Figure 4: Sound field separation

Summary

By applying holographic wave expansion and data acquiring via the near field scanner, the comprehensive 3D directivities of a transducer at any point outside the scanning surfaces can be obtained. The measurement can be performed in normal office room. With the field separation the direct radiated sound field can be nicely identified. Comparing to a conventional far field measurement in an anechoic room, the new method saves construction cost and measuring time but provides more accurate results.

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