An overview of papers in the field of loudspeakers and sound reproduction produced by the chair of SPS' on AM of the TU/e

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February 20, 2024

Abstract

An overview of papers in the field of loudspeakers and sound reproduction is presented. These papers are scattered in time and at various places, however, therefore they are here placed in there own context and all together. Most—if not all are—pdf's of these papers are available at `https://www.sps.tue.nl/rmaarts/`.

1 Sound radiation

The Nijboer-Zernike (NZ) approach in Optics is a method to compute optical point-spread functions for circular, focused, optical systems in the presence of aberrations. The approach has been devised by Zernike (1934) and his student Nijboer (1942), and the key features of it are expansion of non-uniformities in the exit pupil as a series of Zernike circle polynomials together with a convenient analytic result for the contribution of each of these polynomials to the point-spread function. In recent years, the Nijboer-Zernike approach has been applied to solve forward and inverse problems in acoustical radiation from a flexible circular piston surrounded by a rigid infinite planar set (baffle) and from a flexible spherical cap on a rigid sphere. See [1] for an introduction, which cites most of our papers on this topic, including [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]. Most of those papers including more background on the Extended Nijboer-Zernike (ENZ) theory is at `https://nijboerzernike.nl/` and all papers and beyond sound radiation are at `https://www.sps.tue.nl/rmaarts/`. Note the ENZ-theory applied to acoustical radiation is also referred to as ANZ.

2 Loudspeakers

The work on loudspeaker radiation is covered in Section 1 above. The work on canceling unwanted loudspeaker signals is in [14]. Optimally sensitive and efficient compact loudspeakers for low audio frequencies are discussed in [15, 16, 17]. Other special topics are discussed in the sections below.

3 Sound reproduction

The improvement of sound reproduction in particular of limited size systems is in [16].

3.1 Position Independent Stereo PI-Stereo

Enlarging the sweet-spot for stereophony by time-intensity trading is discussed in [18, 19, 20, 21].

3.2 Personal Sound

A way to focus sound into a small area, also known as personal sound, is discussed in [22].

3.3 Stereo to multi-channel sound Conversion

A method to convert stereo to multi-channel sound is presented in [23, 24, 25, 26].

3.4 Stereo base widening (Incredible Sound)

Phantom sources applied to stereo-base widening are discussed in [27, 28, 29, 30, 31].

4 Signal processing algorithms

Derivation of an optimal directivity pattern for sweet spot widening in stereo sound reproduction [21], and efficient tracking of the cross-correlation coefficient [32].

5 Bandwidth extension

There is the book 'Audio Bandwidth extension. Application of Psychoacoustics, Signal Processing and Loudspeaker Design' [33], and papers [34, 35, 36].

6 Loudness

During loudspeaker listening tests, it is important that the various loudspeaker are equally leveled in loudness. Various recommendations and methods are treated in [37, 38, 39]. An important conclusion appeared that the A-weighting method is not recommended for accurate loudness balancing, the B-weighting gives much better results.

7 Cooling

These works deal with an overview and implementation of the principles of heat transfer and acoustics related to a promising alternative for fans: synthetic jet cooling. The benefits, the background and the principles underlying the physics are treated. The problems with optimisation through numerical analysis are highlighted [40]. Another paper [41] discusses the experimental results in terms of heat transfer and noise for a special embodiment: an acoustic dipole cooler. Patents for cooling implementations are discussed in [42, 43].

8 Arrays

An extended version of the Zernike polynomials, known as ENZ, see Sec. 1, was applied to solve forward and inverse problems in acoustic radiation of a flexible circular piston surrounded by a rigid infinite plane (baffle) and of a flexible spherical cap on a rigid sphere, showing that the latter is quite similar to that of a real loudspeaker, see [2, 4]. The use of several loudspeakers arranged in an array allows special radiation characteristics. For example, one can increase the sweet spot area during stereophonic listening by making use of inter aural time differences, this system was called position-independent stereo [18], see Sec. 3.1. Another application is to direct or aim the sound to a listener without disturbing others, this is known as personal sound, see Sec. 3.2. Yet another application is to use quadratic phase arrays to design loudspeaker arrays that radiate just like a single loudspeaker [44]. For loudspeaker radiation calculations the Struve function is often needed, simple approximations have been derived for this, see [45, 46] and Sec. 9.

9 Struve function approximations

Approximation of the Struve function H_1 occurring in impedance calculations is presented in [45, 46].

10 Crossover filters

Methods for the design and simulation of crossover filters are presented in [47, 48, 49, 50, 51].

11 Bass

The development, improvement, and hardware implementation of bass enhancement/restoration systems exploiting the natural psycho-acoustic phenomenon known as the 'missing fundamental' is studied [16]. Small loudspeakers are in general not capable of reproducing low-frequency notes, but by exploiting auditory illusions one can use either the virtual pitch phenomenon to shift the low frequencies to a higher frequency band where the loudspeakers are capable, this is sometimes referred to as Ultra Bass [52] or, one can map the very low frequency to one single frequency where the loudspeaker is designed for high efficiency, this is sometimes referred to as Bary Bass [53]. On the other hand, if the loudspeaker is capable of radiating low frequencies, but if they are not present in the music, those frequencies can be derived from the music using a bandwidth extension scheme, this is sometimes referred to as Infra Bass [54]. Finally, the audio quality, especially from high Q low-frequency sound transducers, can be improved by attenuating decay parts of bass signals thereby reducing sustain or ringing for bass notes, this is sometimes referred to as punchy bass [55] .

12 LS efficiency, High- Low-, Optimal-Force Factor (Bl)

Normally, low-frequency sound reproduction with small transducers is quite inefficient. This is shown by calculating the efficiency and voltage sensitivity for loudspeakers with high [59, 60], medium, and, in particular, low force factors [61, 62]. For these low-force-factor loudspeakers a practically relevant and analytically tractable optimality criterion, involving the loudspeaker parameters,will be defined. Actual prototype bass drivers are assessed according to this criterion. Because the magnet can be considerably smaller than usual, the loudspeaker can be of the moving-magnet type with a stationary coil. These so-called low-Bl drivers [61, 62] have a high efficiency, however, only in a limited frequency region. To deal with that, nonlinear processing essentially compresses the bandwidth of a 20–120-Hz bass signal down to a much more narrow span. This span is centered at the resonance of the low-Bl driver, where its efficiency is maximum. The signal processing preserves the temporal envelope modulations of the original bass signal. The compression is at the expense of a decreased sound quality and requires some additional electronics to mitigate this effect. This new, optimal design has a much higher power efficiency as well as a higher voltage sensitivity than current bass drivers, while the cabinet may be much smaller [15, 17, 56, 63, 64].

13 Headphones

Headphone virtualizers are systems that aim at giving the user the illusion that the sound is coming from loudspeakers rather than from the headphones themselves [65, 66, 67, 68].

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