INNOVATION PROJECT

MEASUREMENT OF LINEAR AND NON-LINEAR DIRECTIVITY CHARACTERISTICS ON PHASED ARRAY LOUDSPEAKER SYSTEMS

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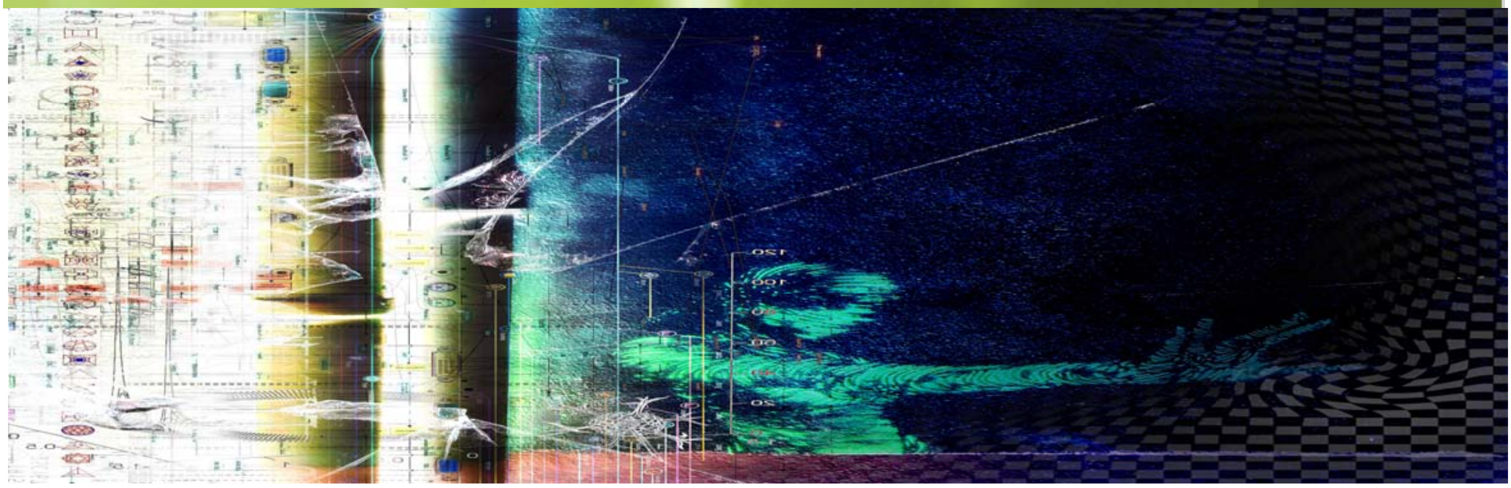

This project is about investigating dynamic non-linear behavior of loudspeaker units. Non-linear coupling from input voltage to sound pressure produces input signal magnitude dependent harmonic distortion which severely degrades the performance of speakers especially when put into array configurations. We have looked into the magnitude of the non-linear behavior by modelling, we have implemented in real time electronics and tested algorithms for linearizing speakers dynamically, and we have set up a measurement system by which we can verify our designs. For the participating companies the results are likely to be directly applicable in future commercial products, and as such the objectives of the project have been met.

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About the publication

This publication and possible comments and discussions can be downloaded from www.danishsound.org.

The content of this publication reflects the authors' point of view and not necessarily the view of the Danish Sound Innovation Network as such.

About the network

Danish Sound Innovation Network is an innovation network funded by the Danish Agency for Science, Technology and Innovation. The Network is hosted by the Technical University of Denmark and is headed by Director, Associate Professor, PhD Jan Larsen.

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This publication is the result of an innovation project, an instrument to strengthen the cooperation between knowledge institutions and private companies. The primary goal is to promote innovation by combining accessible/existing research and technologies with creative uses in order to facilitate the creation of new products, services or experiences. Innovation projects are mainly short term feasibility studies conducted on a pre-competitive level.

PREFACE

This publication is the result of an innovation project entitled **Measurement of Linear and Non-linear Directional Characteristics on Phased Array Loudspeaker Systems**. The project is financed by the Danish Sound Innovation Network through a grant from the Danish Agency for Science, Technology and Innovation. The project is completed in the period 2013, 1 September – 2015, 31 January and managed by Aarhus University School of Engineering, project managers Jakob Juul Larsen and Lars G. Johansen. Additional project participants are: Kim Rishøj, Søren H. Nielsen, and Tore A. Skogberg.

INTRODUCTION

BACKGROUND

The motivation for this project was to be able to control the directivity characteristics of phased array loudspeaker panels in a more refined and satisfactory way. Traditionally, controlling directional sound is heavily based on passive or active linear pre-filtering of the signal fed to the individual speaker units. The *non-linear* behavior of typical loudspeaker units however deteriorates the capability of accurately producing sound beams.

More companies have shown considerable interest in teaming up with Aarhus University in order to make advances in the field of understanding the implications of using non-linear speaker units in phased array systems - and ultimately being able to correct for undesirable behavior of such.

OBJECTIVE

Primary objectives of the project encompass:

1. gaining more knowledge of the non-linearities involved in producing sound using dynamic loudspeaker,
2. setting up a suitable model of a non-linear loudspeaker,
3. designing non-linear digital filters to correct for the inherent non-linear mechanical behavior of the speaker,
4. implementing and verifying the functionality of such filters, and
5. realizing a full phased array speaker system with non-linear correction filters as well as directivity control filters.

A secondary objective is to setup a measurement and correction platform at Aarhus University, Audio Technology and Acoustics Lab for test and development of digitally controlled phased array speaker systems, i.e. setting up a multi-channel system comprising 24 channel signal processing hardware, 24 calibrated power amplifiers, and preferably a 48 channel sound pressure acquisition system.

IMPACT/EFFECT

The project serves as a platform of learning. It is believed by the participating organizations that the results and other outputs from the project are either directly applicable as a feed into future products and/or will enhance and ease the development of future products.

METHODS AND RESULTS

THEORY

Understanding the loudspeaker unit's conversion of input voltage to sound pressure is largely based on modelling the electronic, the mechanic, and the acoustical parts of the unit. Such modelling has been known and used since about 1970, where Thiele and Small published the set of TS-parameters which in a lumped parameter model fairly accurately describes the transducer properties operating under *small signal* conditions. That is *linear* modelling of the transducer is well established. In the late eighties Klippel took on setting up models of the loudspeaker operating under *large signal* conditions. The two main issues to handle are:

- The large excursion of the mechanical system which means that the voice coil is not always subject to a constant magnetic field.
- The mechanical limits of the diaphragm suspension. Long before the suspension is stretched out totally, the motion of the diaphragm has entered a non-linear region.

Both issues mean that when fed with high input electrical signals, the loudspeaker cannot be expected to linearly produce sound pressure. Luckily, the non-linearities mainly show up as harmonic components, so a perfect sine electrical input is turned into a sound pressure consisting of the sum of the fundamental frequency and 2^{nd}, 3^{rd}, 4^{th}, and so on harmonic components which magnitudes depend on the magnitude of the input signal.

METHOD AND EXPERIMENTS

According to the theory we have employed Klippel's non-linear models of the loudspeaker and his proposals for digital correction algorithms based on pre-filtering and measurement(s) feedback. A multichannel DSP correction system has been set up, and facilities for simultaneous voltage and current measurements are realized. As step one instead of current feedback we have used sound pressure obtained in microphone measurements. However not practical from a product point of view, sound pressure measurements provide an easy to interpret picture of the corrections obtained.

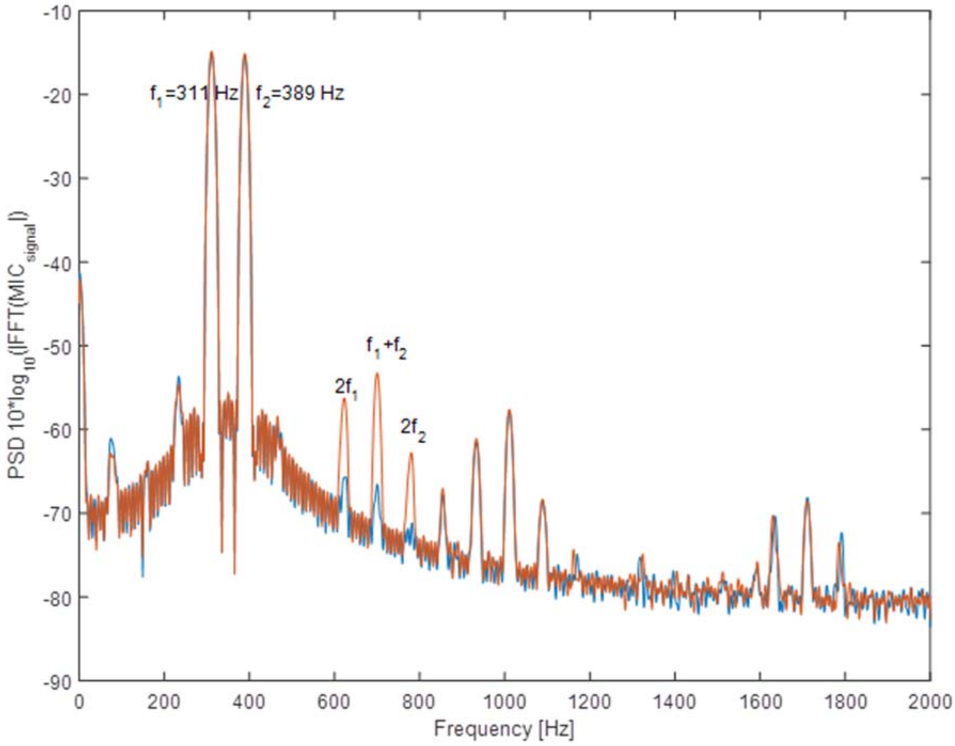
Full-range loudspeaker units are mounted in a line array, and preliminarily a four channel system is investigated.

As a matter of reference for the position/excursion of the loudspeaker diaphragm when playing additionally we have included a laser based acquisition scheme where diaphragm velocity is measured. Laser measurements are not feasible in commercial products but serve a purpose in the digital correction algorithm development phase.

RESULTS

To support the project we have thankfully received a grant from Industriens Fond and so being able to invest in proper laboratory equipment for the test setups.

Using simultaneous measurements of input voltage and current flowing through the loudspeaker voice coil, the hardware system and the implemented algorithms allow us to correct non-linear loudspeaker units to a degree where a substantial decrease of the 2^{nd}, 3^{rd} and higher order harmonic components is observed. We have shown this to be a fact for individual speakers, and this result complies very well with the primary objective. As an example, see the figure below, a dual tone input signal is fed to the loudspeaker. The correction algorithm is optimized to reduce the 2nd order harmonic distortion only, and we observe a decrease in that component of approximately 10 dB (blue power spectrum).



An immaterial but no less important outcome of the project so far is an increased interest from engineering students at Aarhus University in the fields of applied audio technology and acoustics. Also, this project has led to an emphasized focus on the fact that there is an industry which asks for qualified candidates in the field of audio technology and acoustics – and that Aarhus University can and should support that demand. We have increased the number of bachelor projects conducted in closed cooperation with the industry, and we have set up and put in motion two completely new courses within the field with more to come.

At the time of writing results are being produced based on the four channel setup where also the directivity control filters are implemented. We have engaged a master degree student to continue the work on the four channel array setup.

CONCLUSION

Through this project we have gained substantial knowledge on how to handle dynamic non-linearities in loudspeaker units particularly with them being put in array configurations. A comprehensive experimental measurement setup has been devised, and as part of that we have implemented a non-linear DSP based correction system building on patented algorithms. Results show that our system is capable of dynamically reducing harmonic distortion produced by the loudspeaker.

Obtaining such conceptual viability results of the technology is a major step forward in bringing this correction technique to life in commercial products. Our participating companies TC Electronic working in the fields of instruments amplification, digital correction, and effects processing, and SoundFocus setting up dedicated loudspeaker array solutions both have had a great yield of this project. Understanding how to dynamically correct loudspeaker units in array configurations have the potential to lead to completely new applications of array panels and to otherwise unrealistic features in such.

Dynamic non-linear characteristics of speakers have greater detrimental impact on the performance, in arrays particularly, that one might think, and at Aarhus University, Audio Technology and Acoustics Lab. we now have a much better understanding of such as well as an experimental correction system which can serve as a technical support platform for external partners in the future.