Application of parametric and non-parametric techniques to electroacoustic transfer function analysis

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JOURNAL DE PHYSIQUE IV
Colloque C5, supplément au Journal de Physique III, Volume 4, mai 1994

Application of parametric and non-parametric techniques to electroacoustic transfer function analysis

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Abstract: Electroacoustic devices or systems transfer functions are usually described by means of amplitude and phase Bode plots. They are obtained from usually large data series of excitation and response values. Acoustic set-up requirements vary considerably, from normal room to anechoic conditions, from complex instrumentation to simple sweeping ensembles. Filter frequency analysis, cross-spectral estimation by means of the discrete Fourier transform, time-delay spectrometry and the cepstral analysis methods are non-parametric examples. Model based techniques can be classified as identification techniques. They usually employ a limited set of parameters and achieve high information compression ratios and non-redundancy, flexibility and adequacy to convert to other types of models. In the present paper the most important established techniques for electroacoustic transfer function measurement are surveyed in their principles, possibilities, instrumentation and set-up requirements. A comparison is made with an input-output rational model based parametric technique, developed in the F.E.U.P. Practical results are reported, showing the accuracy obtained through this technique when applied to the measurement of a real full-range loudspeaker system. Nevertheless some difficult aspects still persist. In our point of view, a promising new way is ahead for measurement techniques in the electroacoustic field.

1. Introduction

The description of electroacoustic transfer functions, for instance, on the main axis of microphones and loudspeakers, has traditionally been done by means of amplitude and phase Bode plots of the response.

A loudspeaker could be classified as a very wide band-pass system. In fact, for a low cut-off of 20 Hz and a high cut-off of 20 kHz, the theoretical centre frequency is 632 Hz and a hypothetical Q value of 0.032 (!) results.

For a reasonable resolution, a large number of data results from measurements of acoustic and electrical variables. For instance in a full-range analysis using third-octave bands a set of 60 real values is required and in a dual-channell FFT run at least some hundreds of values are obtained.

Of course handling and storing large amounts of data has nowadays been turned into an easier and easier task. A different perspective is needed however when a specific interpretation of the data is required. Possessing a large number of data is not a sufficient condition for a powerful and useful subsequent analysis to be possible. For instance, when a spectral pass-no-pass test is performed in a production line, things are not critical in this respect, but, on the other hand, a fine detailed description of the response is required in transducer development activities.

Mainly, smoothness and shape oriented criteria are applied over the response curves in order to establish a ranking of performance quality.

2. Non-parametric methods

To be referred, for instance, the transfer function estimation methods by filter frequency analysis, the discrete Fourier transform based methods like the autospectral and the cross-spectral estimation, the time-delay spectrometry (TDS) method and the cepstral analysis method.

Original data natures of these non-parametric methods may be of two kinds: amplitude and phase detectors readings for spot frequency type methods and series of instantaneous time-sampled values for the others.

Acoustic set-up requirements vary considerably amongst methods, from normal room to anechoic conditions, from simple sweeping ensembles to complex instrumentation. The normal-room methods receive preference because of the lower price of the required set-ups although they have to avoid the inevitable effects of echo signals. Many times time-windowing (T) solves the problem, although imposing a lower limit in the low-frequency range due to the limited basic frequency resolution (1/T). Use of pulse exciting signals and adequate observation time window allow elimination of the reflections on room boundaries effects. This can, though, only be accomplished with success for durations of some milliseconds, what is an obvious limitation, particularly for signals with relevant low-frequency contents. For a reasonable 10 ms time window, a 100 Hz basic resolution is obtained, what is not sufficiently low for many situations. The situation could be alleviated through the use of complementary low-frequency specific methods.

3. Parametric methods

Along with the former non-parametric techniques, a set of model based parametric ones deserve consideration. Models were established either with a physical perspective, in order to quickly connect to the real devices structures, or with a functional one. Model based techniques can essentially be classified as identification techniques, because the goal is invariably to obtain estimates for a limited set of model parameters. They usually achieve some desirable characteristics such as high device information compression ratios and non-redundancy, flexibility and adequacy to convert to other types of models.

Not minimizing a certain validation and standard role that non-parametric techniques, such as the dual-channel FFT analysis method, have fulfilled, parametric alternatives can generally also offer a built-in conversion from parametric to non-parametric results.

This is, for instance, the case of a pole-zero transfer function model representation, which allows direct calculation of magnitude and phase plots. In this sense existing non-parametric oriented evaluation methods can still be applied with consistency. Judging by the results of low frequency parametric modelling of electro-mechanical-acoustical transfer started by Thiele and Small, it can be inferred that, by domain extension, the full parametric description of electroacoustic (EA) devices transfer functions (TFs) can be very important in their development and improvement.

Table 1 - Electroacoustic radiators measurement methods

Types	Locals	Signals	Acquisition	Processing	Resuls
Response tracing	Anechoic chamber	Continuous, sinusoidal	Analog, preamplification and filtering	Analog quadratic detection	Non-parametric
1 channel frequency analysis (anal. or dig.)	Anechoic or reverberation chamber	Continuous, sinus., white or pink noise	Analog (digital), preamplification, filtering, A/D conversion	Analog or digital quadratic detection, narrow band filtering	Non-parametric
2 channel frequency analysis (FFT)	all	Almost all	Digital, preamplification, filtering, A/D conversion	digital ,FFT	Non-parametric
Cepstral Analysis	all	All non sinusoidal	Digital, preamplification, filtering, A/D conversion	FFT, deconvolution	Non-parametric
Time-delay spectrometry (TDS)	all	"chirp"	Analog (digital), preamplification, filtering, A/D conversion	specific, analog or digital	Non-parametric
Transfer Function Identification	all	Impulse and pulse trains	Digital, preamplification, filtering, A/D conversion	Transfer function Identification	Parametric (and non-parametric)

Based on a general rational input-output function model an electroacoustic transfer function assessment method was developed by the authors, at the Faculty of Engineering of the University of Porto [1]. Time windowed sampled input and output signals are collected. Data processing consists mainly on transfer function identification after normalization and synchronization of signals. The method was applied to loudspeaker study where the two collected signals were the electric input current and the acoustic pressure produced at a 1m distance on-axis.

The values of the nominator and denominator polynomials are obtained, minimizing a total squared prediction error measure in accordance to the AIC ("Akaike Information Criterion"), calculated as the difference between the real output and the simulated output values [2]. The transfer function identification method consists on a locally developed version of the former pencil-of-functions method selected amongst a number of relevant methods that were implemented and evaluated in our work. Criteria and software tools for practical application of the new method were also developed [3] with a recursive version currently under refinement.

Table 1 shows a comparison of the most popular electroacoustic radiators measurement methods. Analog and digital hardware are not very different amongst the 4 last methods and so is their ability to be used in quiet normal-room conditions. Use in anechoic chamber can enhance results in all cases due to a longer time slot available. Low-frequency limitations are similar in these 4 methods.

Processing is quite different in all cases, with varying degree of complexity and consequently of speed. The 2-channel frequency analysis is capable of working in real time. The identification method is generally heavier in computational terms. Refined recursive versions and procedures will allow fast performance in the near future.

4. The SAFTE method

Main axis sound radiation and free, far-field, propagation can only introduce a temporal delay in the acoustic pressure signals, corresponding to a broadband linear phase transmission channel. At high frequencies directivity problems become serious because even with small radiators, things rapidly fall off the ka<2 condition and diffraction effects become important [4]. It can be said that the corresponding existence of off-axis response irregularities usually complicated by crossover problems will introduce order increases in the EA TF and additional difficulty in modelling.

The rational model used is:

$$H(z^{-1}) = \frac{B(z^{-1})}{F(z^{-1})} z^{-t} \qquad \text{Pa/V or (Pa/A)}$$

where $B(z^{-1})=b_0+b_1z^{-1}+...+b_qz^{-p}$, $F(z^{-1})=1+f_1z^{-1}+...+f_pz^{-p}$, t ª L/c is the number of delay samples spaced by T; L is the radiator-microphone distance and c is the speed of sound.

The pencil-of functions identification method is essentially an off-line method that uses a linearization of the general identification problem, employing an equation error definition for a rational pole-zero model [1]. Input and output signals from the system under analysis are used.

Processing is in two phases, the preprocessing phase, where collected signals are repetitively first-order low-pass filtered, generating a set of information signals and the main phase, where a Grammian (or inner-product matrix) of these signals is organized and processing results in the calculation of model coefficients, b's and f's. This symmetrical and non-Toeplitz matrix is theoretically singular whenever the model order equals the system order, due to the linear dependence among the information signals [1][5].

The implicit formula developed in the authors' work [1] is the following, where $D = \sqrt{D_1} + \ldots + \sqrt{D_{p+1}}$ and D_i are the diagonal cofactors, p is the model order and q is the 1st order filter coefficient:

$$H(z) = z^{-1} \frac{\left[\frac{1}{D} \sum_{i=1}^{p} \sqrt{D_{p+1+i}}\,(qz^{-1}-1)^{p-i}\right]}{\left[\frac{1}{D} \sum_{i=1}^{p+1} \sqrt{D_i}\,(qz^{-1}-1)^{p+1-i}\right]} .$$

Due to the frequency weighting caused by repetitive filtering, high frequency noise will contribute less to the equation error so achieving more robust solutions.

5. Some practical results

Figures 1, 2 and 3 show 100 kHz sampled pulse test signals (input current-output sound pressure) and the amplitude and phase plots of a conventional 2-way full range loudspeaker transfer function, obtained by dual-channel FFT analysis (solid) and by rational modelling and identification (dashed) over the first 69 samples from the same data record. The model order employed is 8, with a total of 16 coefficients determined for the rational transfer function. Total squared relative output prediction error obtained was 0.0003.

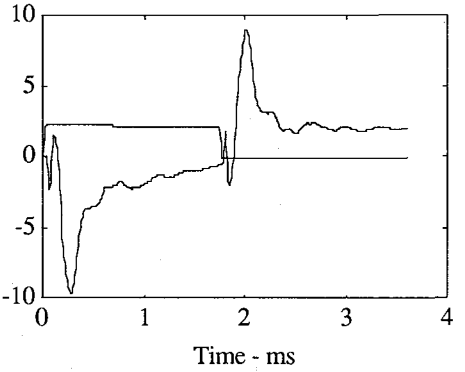

Figure 1 - Time signals

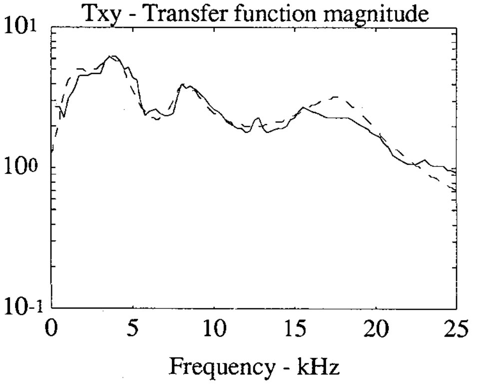

Figure 2

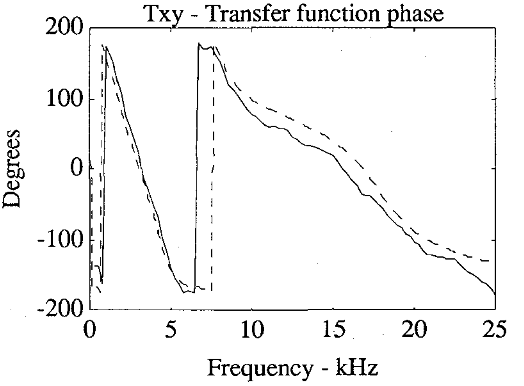

Figure 3

6. Conclusion

Loudspeaker performance evaluation is a delicate and difficult domain. Intrinsic limitations of radiators such as response irregularities are, today, serious enough to justify actual scientific and technologic efforts. High quality is fundamentally related to the uniformity of objective response. Advanced measurement techniques that can enhance correlations between the loudspeaker performance and its global characteristics are so welcome. The exposed instrumental method, taking into consideration the most relevant existing methods to date has achieved an unprecedented global accuracy and compactation of results, in spite of standard hardware resources employed, mainly, due to the TF and identification based conceptual approach. Identification tools, in particular, were developed and created to allow a working system (SAFTE) to be built and used for a number of demonstrative cases. Future work regards an extension to spatial characteristics, establishment of correlations with radiators' characteristics and improvement of LF characteristics.

7. References:

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