

# Direct Path MISO method: Identification of Nonlinear Electro-acoustic Systems

A. Novák \*, F. Kadlec \*, L. Simon \*\*, P. Lotton \*\*

novaka4@fel.cvut.cz

\*Department of Radioelectronics, Faculty of Electrical Engineering, Czech Technical University, Technická 2, 166 27 Prague 6, Czech Republic

\*\*Laboratoire d'Acoustique de L'Université du Maine, UMR CNRS 6613, Avenue Olivier Messiaen, Le Mans, 720 85, France

Identification of nonlinear systems is a current problem in many domains of acoustics and electro-acoustics, such as loudspeakers nonlinearities, nonlinearities of electronic circuits of multimedia devices, nonlinear propagation and more. Almost all the systems we can find in the domain of acoustics and electro-acoustics behave more or less nonlinearly. There is a different behavior at low and high amplitudes of input signals that is accompanied by a presence of additional spectral components in output signal which are not in the input signal. The nonlinearity in such an audio system may cause either a distortion of the sound quality, which has a disagreeable effect on its perception, or a change in timbre of sound, that is positively used in musical instruments. From that point of view, we can divide nonlinear electro-acoustic systems into two categories. First, where the nonlinear behavior is not desired and a system is supposed to be linear, such as loudspeaker, amplifier, etc. In that case the nonlinearities are often considered to be negligible, but they may cause errors whilst measuring such a system [1]. The second category consists of nonlinear systems where the nonlinear behavior is made on purpose to change the timbre of sound, such as a limiter for an electric guitar.

A lot of identification methods have been developed, such as the Volterra Series, higher-order spectra, Hilbert transform techniques, neural networks, NARMAX models, Multiple Input Single Output (MISO) and many others. The Volterra Series model is one of the most known nonlinear models. The Volterra theory states that any time-invariant, nonlinear system can be modeled as an infinite sum of multidimensional convolution integrals of increasing order. These convolution integrals can be represented by multidimensional kernels. As a Volterra kernel is a function of more variables depending on the order, the model representing the nonlinear system contains a lot of coefficients needed to determinate the system. The total number of coefficients required for a Volterra series representation of a nonlinear system increase exponentially with the model order. For that reason, the other methods are trying to replace the Volterra model by a less complicated model.

The aim of our work is to obtain a nonlinear model of the measured system that would allow a simulation of the identified nonlinear system. The MISO model consists of a parallel combination of nonlinear branches containing linear filters and memory-less nonlinearities. The general use of the MISO method is for the nonlinear systems, where the nonlinear contribution is approximately known and the aim is to find linear the filters of the model. In our work, we consider the measured nonlinear system as a black box, with no idea about the nonlinear input output characteristics. Thus, the method is linked to blind identification of the nonlinear system using a power series expansion. If the memory-less nonlinearities of the MISO model are represented by the power-law distortion functions the model corresponds to the Volterra

subclass. The main reason of using of the power-law MISO nonlinear model instead of Volterra model is to provide a simpler model than the Volterra's one. The total number of coefficients required for a MISO model representation of a nonlinear system increase linearly with the model order. According to Bendat, a nonlinear system based on a nonlinear differential or integrodifferential equation can also be modeled in a MISO framework. In some physical cases, the nonlinear system may be moreover modeled as a memory linear part occurring after the nonlinear memory-less operation [2,3]. This hypothesis is considered in our work.

The excitation signal used for our method is the white noise with zero mean value and defined standard deviation. The advantage of such a signal is that it is broad-band and thus the results can be obtained in one step. Once the measurement is done and the output signal is known, the calculation of the measured system's model can be processed. First of all the decorrelation of the MISO inputs has to be solved. Since the model based on power series is used, the powers of the input signals, which correspond to the inputs of the MISO model, are mutually correlated and they have to be decorrelated in order to find the filters of the model. Then, the power spectral densities and cross spectral densities between the inputs and the output are calculated and the filters of the model are estimated. The given MISO model, which represents the measured nonlinear system, is able of reconstruction of any input signal with amplitude less then three times the standard deviation of the excitation signal.

The method has been verified first of all theoretically on nonlinear models, such as limiter, dead zone system, and many others and then on real nonlinear devices such as a diode circuit, an audio limiter and audio amplifier. The method has given the nonlinear models of the analyzed objects. To verify the functionality of the model, the same input signal has been put into the real system and its nonlinear model and the both outputs has been observed and compared. The outputs matched in all the cases. The method has been also tested on loudspeaker nonlinearities identification, but with not correct results due to the undesirable noise, that might have been correlated with the excitation white noise. The method has been also compared with the sweep-sine method [4]. Based on the results of the comparison, the MISO power series method is nowadays tested with the sweep-sine excitation signal in stead of the white noise. The firs measurements have given very hopeful results.

## References:

- [1] A. NOVÁK, F. RUND: *Systematické chyby při analýze nelineárních systémů*, In Technical Computing Prague 2007 [CD-ROM]. Praha: Humusoft, 2007, ISBN 978-80-7080-658-6.
- [2] A. NOVÁK: *Identification of Nonlinear Systems: MISO modeling*, In Poster 2007 [CD-ROM]. Prague: CTU, Faculty of Electrical Engineering, 2007,
- [3] A. NOVÁK: *Identification of Nonlinearity of Electro-acoustic Systems using a Direct Path MISO Method*, In 19th International Congress on Acoustics [CD-ROM]. Madrid: Sociedad Española de Acústica, 2007, ISBN 84-87985-12-2
- [4] F. KADLEC, A. NOVÁK: *Comparision of Measurements Method for Analysis Electro-acoustic Systems with Non-linearities*, In 19th International Congress on Acoustics [CD-ROM]. Madrid: Sociedad Española de Acústica, 2007, ISBN 84-87985-12-2

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