

Method for adaptive high-frequency measurements and automated behavioral modeling of microwave active devices

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Abstract—The project focuses on limiting the total cost of measurements and modeling of microwave active devices. The response surface methodology is adapted to large signal measurements in the course of this work. The methodology is profiled and optimized against the computational load, and the real-time evaluation is enabled. The dynamic constraints expand the use of the methodology to high-power applications. Finally, the performance of the response surface methodology is assessed versus well established empirical modeling method. Not only the behavioral models outperform the empirical ones in terms of accuracy, but also allow to overcome mutual weaknesses in a hybrid modeling technique.

Index Terms—response surface methodology, behavioral modeling, design of experiments, active device modeling, adaptive sampling

I. INTRODUCTION

THE fast advancements in the measurement capabilities of microwave instrumentation is not followed by the related development in design of experiments and modeling. Exponential growth of the number of samples with the number of input dimensions entails unfeasible experiment evaluation times. Especially, variables such as temperature and load-impedance show relatively high tuning time.

Another problem arises in the field of modeling of nonlinear devices. While empirical models can partially address the curse of dimensionality, their applicability is very device-specific, and as such, limited. The development or even a modification of the empirical model demands high experience and knowledge of undergoing physical phenomena. Whereas it is still feasible to propose an empirical model for the basic devices, it is nearly impossible to write a system of analytical equations for complex circuits without knowing the details of the technology.

As a result, the modeling of complex circuits, or packaged devices is condemned to use behavioral "black-box" models. However, their lack of physical bonds between the outputs and inputs manifests in very poor extrapolation capabilities. Therefore, the measurements must include the whole space of input variables specific for the model application. This usually requires intensive measurements, and if the number of input dimensions is high, the experiment complexity may be too large. Moreover, the behavioral description of the nonlinear

microwave elements entails also a very high output dimensionality, which results in extensive computational effort. The experiment and modeling complexity can be again reduced by a very experienced operator, as one can accurately trim the input and output space of variables. However, the demand for vast experience can be perceived in terms of cost too. In any way, the total cost of multivariate characterization and modeling remains very high.

Therefore, the aim of the project, as well as the entire PhD research, is to minimize the total cost of the experiment and modeling understood not only as the measurement time, but also as the cost of gaining the required experience.

II. STATE OF THE PROJECT

Before the start of the project the Response Surface Methodology (RSM) was identified as a method that may potentially allow fully automated modeling and measurements of microwave active elements. In the RSM the behavioral models are extracted consecutively with performing measurements, which can be perceived as an active learning method. Since the RSM originates in geology and mechanics, it is not well suited to many microwave-specific problems. Therefore, the project mainly focused on adapting the RSM to microwave measurements of active elements.

Firstly, the RSM methods were profiled against their computational load. In order to limit the number of modeled quantities the compact nonlinearity measure was developed [1]. It is a generic quantity that reflects total nonlinearity of the device under test, and can be used if a large number of quantities has to be considered in the final description of nonlinear element. Then, the real-time RSM evaluation was enabled [2]. The RSM was split into two concurrent threads, one responsible for modeling, and one responsible for sampling and measurements. The concurrent evaluation is supported by thorough analysis of its impact on the RSM performance.

A very important outcome of the project is including microwave-specific constraints in the RSM. The adaptive sampling algorithms were modified in order to handle the fixed frequency grid that originates in the instrument calibration procedure [3]. Next, the RSM was enabled for the high-power microwave measurements. Two methods of constraining the input space of variables were developed. The first one is based on the concept of dynamic constraints, and is model independent. Thus, it allows potentially destructive measurements on scattered grids, even if RSM is not employed. The

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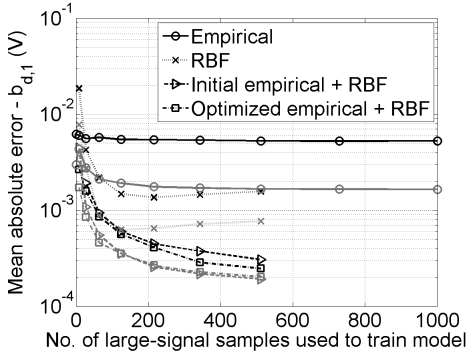


Fig. 1. Mean absolute error for first harmonic of scattered wave at the HEMT drain port as a function of the number of samples used to train the model. Real parts - black lines, imaginary parts - gray lines.

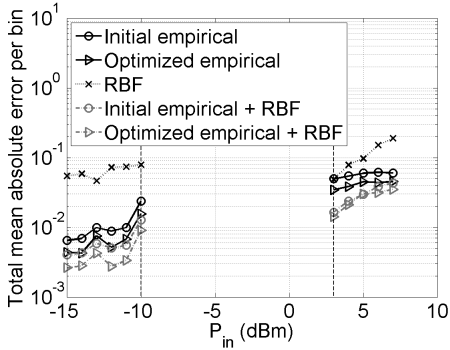


Fig. 2. Total mean absolute error of the models in the extrapolation regions per bin along input power P_{in} . The vertical dashed lines delimit the interpolation and extrapolation regions.

method has been already evaluated in the measurements of GaAs HEMT, and a corresponding publication will follow. The second technique relies on the model and measurement uncertainty. The constraints have been assessed by means of simulations, and they show very promising results.

Finally, the RSM was compared with the well-established empirical model, namely Chalmers model, and it was shown that RSM has better interpolation capabilities [4]. Afterwards, the empirical models were complemented with RSM, which allowed combining the excellent interpolation and extrapolation features of two approaches, and overcome their limitations [5]. The performance of the hybrid model (empirical + RBF) is shown in Fig. 1 and Fig. 2. It is worth noting that the resultant hybrid model can be extracted fully automatically, which is a significant advantage over a demanding optimization of empirical models.

III. FUTURE WORK AND CAREER PLANS

A wide range of possible future works opens up. At least three main directions can be pointed out. First, the computational performance of the RSM should be further optimized, especially, for the adaptive sampling algorithms. Another direction worth investigating is employing data mining methods to estimating the optimal initial design of experiments and to determining the best RSM configuration. The third direction is expanding the range of applications. A very interesting activity

would be to design a microwave circuit using the behavioral model extracted with the RSM.

I have not yet decided on the specific career plans. I have just finished writing the thesis, and I will make decision in the following months while waiting for the defense. I consider going to R&D industry, as well as purely academic career. I also ponder making a leap to entrepreneurship, since I believe that RSM can bring value to many applications.

IV. IMPACT OF THE MTT-S FELLOWSHIP

The MTT-S graduate fellowship gave me the opportunity to attend IMS, EuMC, and INMMiC conferences in 2015. Many valuable discussions I had led to new ideas and provided necessary boost to my research. I strongly believe that the established network will pay off in the future with further developments and applications of the RSM. The fellowship made me think more broadly, and I would strongly recommend the fellowship to anybody.

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