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Cost-Efficient Microwave Design Optimization Using Adaptive Response Scaling

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Abstract
In this paper, a novel technique for cost-efficient design optimization of microwave structures has been proposed. Our approach exploits an adaptive response scaling that ensures good alignment between an equivalent circuit (used as an underlying low-fidelity model) and an electromagnetic (EM) simulation model of the structure under design. As the adaptive scaling tracks the low-fidelity model changes both in terms of frequency and the response level, it exhibits better generalization capability than traditional (e.g., space mapping) surrogates. This translates into improved design reliability and reduced design cost. Our methodology is demonstrated using two examples of microstrip filters and compared to several variations of conventional space mapping.

Keywords: Computer-aided design, microwave filters, EM-driven design, surrogate-based optimization, space mapping, adaptive response scaling

1 Introduction

Electromagnetic (EM)-simulation-driven design closure is an important step of the microwave design process. It typically aims at adjustment of geometry parameters of the structure at hand (e.g., a filter) to ensure that given design specifications (concerning, e.g., return loss) are met (Koziel and Bekasiewicz, 2015). Deviations from the ideal/required characteristics are normally due to inaccuracies of the simplified representations—such as equivalent circuit models—utilized to obtain the initial (or pre-tuning) design.

For the sake of automation, it is advantageous that the EM-based design closure is conducted through numerical optimization. This, however, may be computationally expensive when conventional off-the-shelf algorithms are utilized. Numerous techniques have been proposed to speed up EM-driven

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design, most of which rely on surrogate-based optimization (SBO) paradigm (Koziel, Yang and Zhang, 2013). These include many variations of space mapping (SM), e.g., (Bandler et al. 2004; Koziel, Bekasiewicz and Kurgan, 2014; Sans *et al*. 2014) response correction techniques (Echeverria and Hemker, 2005; Koziel 2010; Koziel and Leifsson, 2013) utilization of artificial neural networks (Gorissen *et al*. 2011), as well as simulation-based tuning and tuning space mapping (Cheng, Bandler and Koziel, 2012). Furthermore, availability of cheap adjoint sensitivities (Basl, Bakr and Nikolova, 2008; Koziel and Bekasiewicz, 2015) revived, to some extent, the interest in gradient-based optimization (Toivanen *et al*. 2010), also in connection with SBO (Koziel *et al*. 2013; Koziel and Leifsson, 2013). On the other hand, the utilization of adjoints is not yet widespread in the microwave engineering community.

Majority of SBO techniques require a rather careful implementation as well as certain engineering insight into the problem. One of the issues pertinent to, for example, SM, is the necessity of appropriate selection of the type and parameters of the surrogate model (such as preassigned parameters for implicit space mapping (Bandler *et al*. 2004; Bekasiewicz, Kurgan and Kitlinski, 2012)). Straightforward application of such methods may lead to unpromising results, including convergence issues (Koziel, Bandler and Madsen, 2009). Methods such as simulation-based tuning are much more robust yet limited in terms of application scope and software requirements. Other techniques, such as the shape-preserving response prediction (SPRP) (Koziel, 2010), require the fulfillment of specific assumptions concerning the response shape of the structure of interest and as well as relatively complex implementation.

In this paper, we propose a simple adaptive scaling technique for fast design optimization of microwave devices. It is based on tracking the changes (both frequency- and level-wise) of the underlying low-fidelity model (e.g., an equivalent circuit) to ensure good generalization capability of the surrogate model constructed with it. Our approach is demonstrated using two examples of microstrip bandpass filters and compared to several variations of space mapping algorithms.

2 Surrogate-Based Optimization Basics

Let $\boldsymbol{R}_f(\boldsymbol{x})$ be a response of the EM-simulated (high-fidelity) model of a device (e.g., filter) under design, where $\boldsymbol{x}$ is a vector of adjustable (geometry) parameters, and $\boldsymbol{R}_f$ represents relevant responses such as *S*-parameters versus frequency. Let $\boldsymbol{R}_c(\boldsymbol{x})$ denote the low-fidelity model of the same device, e.g., an equivalent circuit. The problem to be solved is

$$\boldsymbol{x}^* = \arg\min_{\boldsymbol{x}} U(\boldsymbol{R}_f(\boldsymbol{x})) \tag{1}$$

where U encodes given design specifications, and $\boldsymbol{x}^*$ is the optimum design to be founds.

According to the SBO paradigm (Koziel, Yang and Zhang, 2013), direct solving of (1) is replaced by an iterative procedure

$$\boldsymbol{x}^{(i+1)} = \arg\min_{\boldsymbol{x}} U(\boldsymbol{R}_s^{(i)}(\boldsymbol{x})) \tag{2}$$

where $\boldsymbol{x}^{(i)}$, $i = 0, 1, \ldots$, is a sequence of approximations to $\boldsymbol{x}^*$, and $\boldsymbol{R}_s^{(i)}$ is a surrogate model at iteration i, which is a fast representation of the high-fidelity constructed using $\boldsymbol{R}_c$.

The most important differences between various realizations of SBO algorithms are in the methodologies for constructing the surrogate model. The most popular SBO approach in microwave engineering is space mapping, where the surrogate is obtained by usually simple correction of the low-fidelity model of the form $\boldsymbol{R}_s(\boldsymbol{x}) = \boldsymbol{R}_c(\boldsymbol{x};\boldsymbol{p})$, where $\boldsymbol{p}$ are the SM parameters extracted or calculated to