Parametric Macromodeling of Time Domain Responses*

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Abstract

This paper shows that accurate parametric macromodels can be computed from transient port responses which are varied by one or more design variables. The poles of the parametric macromodel are guaranteed to be stable by construction, and passivity can be enforced as a post-processing step.

1 Introduction

Accurate parametric macromodeling of high-speed interconnects is of paramount importance for efficient circuit simulation and optimization purposes. A robust multivariate extension of the Orthonormal Vector Fitting technique (OVF) is introduced in [1][2], which accurately models parameterized frequency responses with a highly dynamical behavior. Unfortunately, the algorithm is not directly applicable to the macromodeling of parameterized time-domain responses. The main difficulty lies in the representation of the multivariate transfer function, which does not guarantee an overall stability of the poles. A direct evaluation of the multivariate macromodel for various parameter combinations may therefore lead to unstable time-domain simulations, which is undesired. A new approach is presented in [3], which computes guaranteed-stable parametric macromodels from frequency-domain or time-domain responses. It is also shown in [3] how the passivity of the parametric macromodel can be enforced by means of perturbation.

2 Parametric Macromodeling using MOVF

2.1 Macromodel Representation In the Multivariate Orthonormal Vector Fitting (MOVF) technique [2], the parametric rational macromodel $R(s,\vec{g})$ is represented as the ratio of a multivariate numerator $N(s,\vec{g})$ and denominator $D(s,\vec{g})$

$$R(s,\vec{g}) = \frac{N(s,\vec{g})}{D(s,\vec{g})} = \frac{\sum_{p=0}^{P}\sum_{\vec{v}\in V} c_{p\vec{v}}\phi_p(s)\varphi_{\vec{v}}(\vec{g})}{\sum_{p=0}^{P}\sum_{\vec{v}\in V} \tilde{c}_{p\vec{v}}\phi_p(s)\varphi_{\vec{v}}(\vec{g})} \quad (1)$$

where s represents the complex frequency variable, and P the predefined maximal order of the frequency-dependent basis functions $\phi_p(s)$. The basis functions $\varphi_{\vec{v}}(\vec{g})$ are multivariate basis functions, which depend on a parameter vector $\vec{g} = \{g^{(n)}\}_{n=1}^{N}$, containing N real geometrical parameters. Such a basis function is defined as the product of N real univariate basis functions whose order is denoted by subindices v_n.

$$\varphi_{\vec{v}}(\vec{g}) = \varphi_{v_1}(g^{(1)})...\varphi_{v_N}(g^{(N)}), \forall\vec{v} = (v_1,...,v_N) \in V \quad (2)$$

V is a set which contains all distinct tuples $\vec{v}$ with non-negative multi-indices $V = \left\{(v_1,...,v_N) | \{0 \le v_n \le V_n\}_{n=1}^{N}\right\}$, where V_n represents the predefined maximal order of univariate basis functions $\varphi(g^{(n)})$. The coefficients $c_{p\vec{v}}$ and $\tilde{c}_{p\vec{v}}$ in (1) are then iteratively solved for iteration step $t = 1,...,T$ by minimizing the Sanathanan-Koerner cost function ($D^{(0)}(s,\vec{g}) = 1$) [4].

$$\min_{c_{p\vec{v}}^{(t)},\tilde{c}_{p\vec{v}}^{(t)}} \sum_{k=0}^{K} \left| \frac{N^{(t)}(s,\vec{g})_k}{D^{(t-1)}(s,\vec{g})_k} - \frac{D^{(t)}(s,\vec{g})_k}{D^{(t-1)}(s,\vec{g})_k} H(s,\vec{g})_k \right|^2 \quad (3)$$

An additional relaxation constraint can be used to improve the convergence properties if the data is contaminated by noise [5].

2.2 Choice of basisfunctions The frequency-dependent basis functions $\phi_p(s)$ are chosen as orthonormal rational functions (see [2]), which are based on a prescribed set of stable poles. These poles are selected as complex conjugate pairs with small real parts and the imaginary parts linearly spaced over the frequency range of interest, just like the univariate case [6] [7].

The parameter-dependent basis functions $\varphi_{v_n}(g^{(n)})$ are also rational functions, which are chosen in partial fraction form as a function of $jg^{(n)}$. The poles of the fractions are chosen as complex pairs which have real parts of opposite sign, and imaginary parts linearly spaced over the parameter range. A linear combination of two fractions is formed to ensure that $\varphi_{v_n}(g^{(n)})$ is a real function [2]. Conjugacy of the poles is not enforced, since the frequency response is not symmetric for $g^{(n)}$ and $-g^{(n)}$.

3 Pole Stability Problem

If the real coefficients $\theta_p(\vec{g})$ and $\tilde{\theta}_p(\vec{g})$ are defined as

$$\theta_p(\vec{g}) = \sum_{\vec{v}\in V} c_{p\vec{v}}\varphi_{\vec{v}}(\vec{g}) \quad \text{and} \quad \tilde{\theta}_p(\vec{g}) = \sum_{\vec{v}\in V} \tilde{c}_{p\vec{v}}\varphi_{\vec{v}}(\vec{g}), \quad (4)$$

then (1) can be rewritten into the following compact form

$$R(s,\vec{g}) = \frac{N(s,\vec{g})}{D(s,\vec{g})} = \frac{\sum_{p=0}^{P}\theta_p(\vec{g})\phi_p(s)}{\sum_{p=0}^{P}\tilde{\theta}_p(\vec{g})\phi_p(s)}. \quad (5)$$

The poles of $R(s,\vec{g})$ are easily found by solving an eigenvalue problem which is based on the minimal state space realization of $D(s,\vec{g})$. It is clear that these poles will depend on the actual values of $\tilde{\theta}_p(\vec{g})$, which vary as a function of the geometrical parameters. Even though the prescribed poles are chosen to be stable, it is not guaranteed that the relocated poles will remain in the left half plane for all possible values of $\vec{g}$ (within the parameter ranges). Therefore, a direct evaluation of the parametric macromodel for various parameter combinations may lead to unstable time-domain simulations which is undesired. Some analytic criteria to detect unstable poles, and stability enforcement schemes are topics which require further research [8].

4 Time-Domain Macromodeling

In [3], a new parametric macromodeling technique is presented which computes accurate parametric macromodels from frequency-domain or time-domain responses. The stability of the poles is guaranteed by construction, and passivity can be ensured by means of an efficient perturbation scheme.

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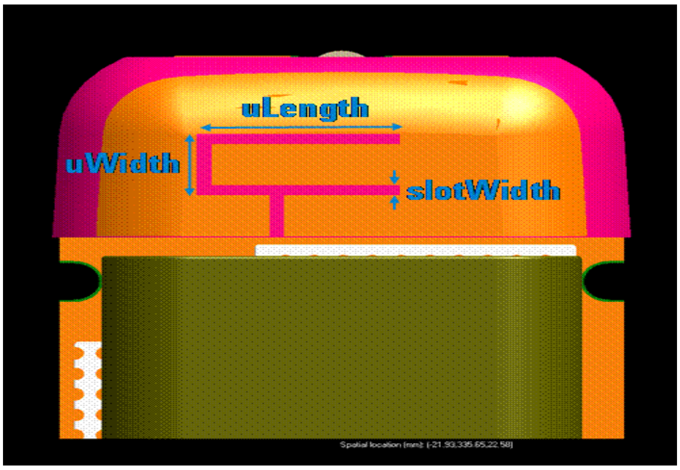

Figure 1: Non-Planar Inverted-F Antenna

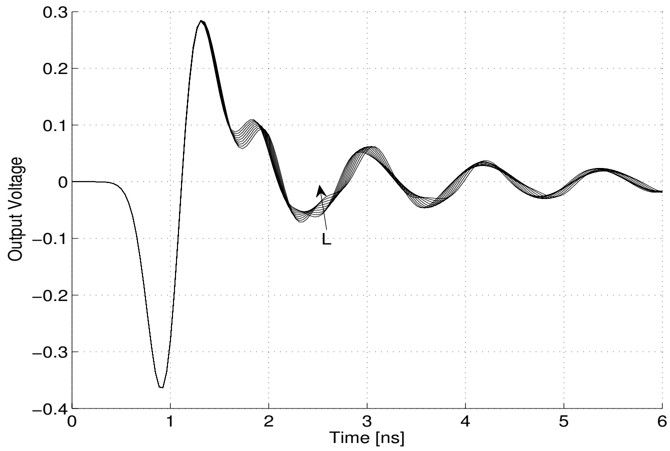

Figure 2: Output voltages for various values of length L

5 Example : Non-Planar Inverted-F Antenna (PIFA)

The technique in [3] is used to compute a bivariate time-domain macromodel of a dual-band non-planar inverted-F antenna with a U-shaped slot of varying length L, shown in Figure 1. The transient response of the antenna is simulated using the Agilent AMDS simulator for 9 different values of L which are uniformly spread over the parameter range L= $[14 - 17.2]$ mm. Figure 2 shows the varying transient behavior of the voltages induced to an injected voltage pulse. The simulated samples are used to compute a parametric macromodel which has stable poles only. Figure 3 shows a zoom of the most dynamical part of the model response for $t = [2 - 6]$ ns. It indicates that the macromodel has an overall smooth, continuous behavior (grey lines) for arbitrary values of L which are selected inbetween the 9 simulation nodes (black lines). The parametric time-domain macromodel can easily be evaluated in the frequency-domain.

6 Conclusions

It is shown in [3] that stable and passive parametric macromodels can be computed from time-domain and frequency-domain responses. This paper applies the technique to compute a stable bivariate time-domain macromodel from simulated transient port responses of a mobile phone PIFA antenna.

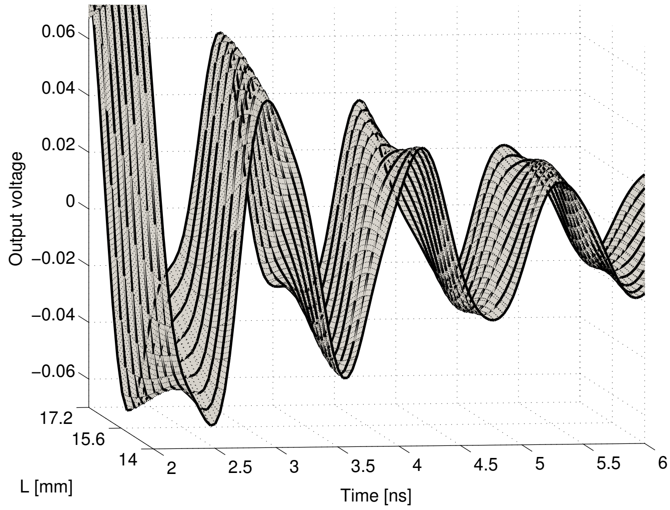

Figure 3: Time-domain response of bivariate macromodel

7 Acknowledgements

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