# Parametric Macromodeling with Guaranteed Passivity for S-parameters

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## I. INTRODUCTION

Robust parametric macromodeling is becoming increasingly important for efficient design space exploration, design optimization and sensitivity analysis of microwave structures. Parametric macromodels can take multiple design variables into account, such as geometrical layout or substrate features, in addition to time or frequency [1].

This paper presents a novel technique to build accurate multivariate rational macromodels for scattering representations that are stable and passive over the entire design space. The technique is validated by a numerical example.

## II. PARAMETRIC MACROMODELING

The goal of the proposed algorithm is to build a multivariate representation $\mathbf{R}(s,\vec{g})$ which accurately models a large set of $K_{tot}$ data samples $\{(s,\vec{g})_k, \mathbf{H}(s,\vec{g})_k\}_{k=1}^{K_{tot}}$ and guarantees stability and passivity over the entire design space. These data samples depend on the complex frequency $s = j\omega$, and several design variables $\vec{g} = (g^{(n)})_{n=1}^{N}$, such as the layout features of a circuit (e.g. lengths, widths,...) or the substrate parameters (e.g. thickness, dielectric constant, losses,...).

### A. Root Macromodels

Starting from a set of multivariate data samples, a frequency dependent rational model in a pole-residue form is built for all grid points in the design space by means of the Vector Fitting (VF) technique [2]. A pole-flipping scheme is used to enforce strict stability [2] and passivity enforcement can be accomplished using one of the robust standard techniques [3]. The result of this initial step is a set of rational univariate macromodels, stable and passive, that we call *root macromodels* being the starting points to build the global parametric macromodel.

### B. 2-D Macromodeling

In this section we discuss the representation of a bivariate macromodel. Once the *root macromodels* are available, the bivariate macromodel $\mathbf{R}(s,g)$ can be written as:

$$\mathbf{R}(s,g) = \sum_{k=1}^{K_1} \mathbf{R}(s,g_k)\ell_k(g) \qquad (1)$$

where the interpolation kernels $\ell_k(g)$ are scalar functions satisfying the following constraints:

$$\ell_k(g) \geq 0,\ \ell_k(g_i) = \delta_{k,i},\ \sum_{k=1}^{K_1} \ell_k(g) = 1 \qquad (2)$$

A suitable choice is to select $\ell_k(g)$ as in piecewise linear interpolation. The model in (1) is a linear combination of stable and passive univariate models by means of a class of positive interpolation kernels [4]. Stability is automatically preserved in (1), as it is a weighted sum of stable rational macromodels. The proof of the passivity preserving property of the proposed technique over the entire design space can be

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found in [5]. The generalization to a multivariate model can be realized by a multivariate interpolation scheme called piecewise multilinear interpolation. The proposed parametric macromodeling technique is general and any interpolation scheme that leads to a parametric macromodel composed of a weighted sum of *root macromodels* with weights satisfying (2) can be used.

## III. NUMERICAL EXAMPLE

### A. *Double folded stub microstrip bandstop filter*

The double folded stub microstrip bandstop filter under study is shown in Fig. 1. The parametric macromodel of the scattering matrix is built as function of the varying length of each folded segment $L \in [2.08$ - $2.28]$ mm and varying spacing between a folded stub and the main line $S \in [0.091$ - $0.171]$ mm over the frequency range $[5$ - $20]$ GHz. All data is simulated by ADS-Momentum[1] over a reference grid of 300 × 60 × 60 samples $(freq, L, S)$.

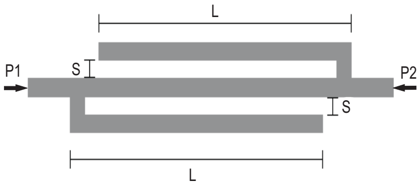

Figure 1. Geometry of the double folded stub microstrip bandstop filter.

441 *root macromodels* are built for 21 values of the length ($L$) and 21 values of the spacing ($S$) by means of VF. The passivity of each model is verified and enforced if needed. A trivariate macromodel is obtained by piecewise multilinear interpolation of all 441 *root macromodels*. Fig. 2 shows the magnitude of the parametric macromodels of $\mathbf{S}_{11}(s, L, S)$ and $\mathbf{S}_{21}(s, L, S)$ for the spacing value $S = 0.091$ mm. The maximum absolute error over the reference grid is bounded by $-64.4$ dB.

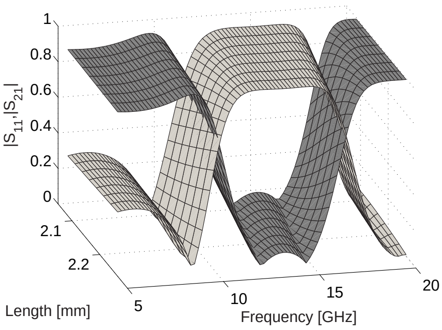

Figure 2. Magnitude of the trivariate models of $S_{11}$ (light grey surface) and $S_{21}$ (dark grey surface) for $S = 0.091$ mm.

## IV. CONCLUSIONS

We have presented a new macromodeling technique for parameterized scattering representations. An efficient and reliable combination of rational identification and interpolation schemes based on a class of positive interpolation operators guarantees the overall stability and passivity of the parametric macromodel.

## REFERENCES

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