

Computer Code for Fast Macromodeling of Large Multiport Systems

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Abstract

Vector Fitting is a robust macromodeling technique for transfer function synthesis in the frequency domain. This paper introduces a new MATLAB routine, called `vectfit3.m`, which is an implementation of the Fast Relaxed Vector Fitting (Fast RVF) method. This routine computes a common-pole rational function approximation from tabulated frequency responses and combines the benefits of relaxation and a fast implementation of the pole-identification step. It is intended to replace the previous `vectfit2.m` routine, because it is significantly more efficient when fitting common-pole transfer matrices with a large number of elements.

1 Introduction

Broadband rational macromodels, based on measurements or full-wave electromagnetic (EM) simulations, are very important for efficient time domain and frequency domain simulation of high-frequency/high-speed interconnection structures, components and systems. The Vector Fitting (VF) technique is a robust macromodeling tool that circumvents the ill-conditioning and unbalanced weighting problems which usually occur in a rational approximation problem [1]. Although the technique was originally developed for the identification of Frequency Dependent Network Equivalents (FDNE's) and power transformers, it has also been successfully applied for the design and modeling of microwave structures [2][3], advanced packaging [4], filter design [5][6], as well as electromagnetic compatibility and signal integrity studies [7].

In the past few years, various enhancements have been introduced to improve the accuracy and convergence of this technique. The use of orthonormal rational functions has been proposed to improve the numerical robustness of the technique [4], and relaxation of the coefficient normalization was introduced to improve the convergence of the pole relocation process [8]. The benefits of both approaches have recently been combined into the Relaxed Orthonormal Vector Fitting (ROVF) method, which is found to be the preferred macromodeling approach [9]. Several other new developments are described in literature, which may further reduce the required amount of VF iterations, see e.g. [10],[11],[12]. Unfortunately, most of these methods suffer from computational inefficiency if the device under study has a relatively large number of ports, although a splitting strategy of the transfer matrix has been considered in [13].

A robust solution to this problem was recently introduced in [14], which allows to identify multiport systems using a common set of poles in a significantly reduced amount of time. This goal is achieved by exploiting the sparsity of the associated least-squares (LS) equations that are solved during the pole-identification step. The method is based the QR decomposition, which does not impose specific restrictions to the data or the modeling process. Numerical results illustrate that significant savings are obtained in terms of computation time and memory resources, while preserving the accuracy of the macromodel. A MATLAB software implementation and manual of this strategy (`vectfit3.m`) is made available on the Vector Fitting website [15].

2 Software package

The vectfit3.m routine approximates a vector of tabulated frequency responses ($s, \mathbf{H}(s)$) by a common-pole rational transfer function that is formulated in partial fraction form

$$\mathbf{H}(s) \approx \sum_{p=1}^P \frac{\mathbf{c}_p}{s - a_p} + \mathbf{d} + s\mathbf{e}. \quad (1)$$

The unknown variables are the residues \mathbf{c}_p and the poles a_p of the transfer function, while the constant (\mathbf{d}) and linear term (\mathbf{e}) are optional quantities. The model as returned by the vectfit3 routine is for convenience expressed as a state-space model of the following form

$$\mathbf{H}(s) \approx \mathbf{C}(s\mathbf{I} - \mathbf{A})^{-1}\mathbf{B} + \mathbf{D} + s\mathbf{E}. \quad (2)$$

A direct estimation of the model coefficients in (1) leads to a non-linear identification problem which can be hard to solve using standard optimization techniques. It was shown in [1] that accurate solutions can be found by solving a linear approximation of the problem in an iterative procedure. This procedure, called Vector Fitting (vectfit.m), starts from an initial guess of starting poles which are relocated in successive iteration steps. Although the convergence properties of the algorithm are equivalent to those of the Sanathanan-Koerner iteration [16], the proposed method is more robust than the polynomial-based formulation because the rational basis functions often lead to a better numerical conditioning if the starting poles are well chosen.

2.1 Relaxation

Experience with the original VF algorithm has shown that its convergence properties become severely impaired if the response to be fitted is contaminated with noise. It was found that this problem is caused by the linearized formulation of the identification problem, and the adopted normalization of the model coefficients [1]. To solve this problem, a modification to the VF algorithm, called Relaxed Vector Fitting (vectfit2.m), was introduced that alleviates these difficulties by introducing a more relaxed non-triviality condition as an additional row in the system matrix [8]. It is found that this constraint leads to more accurate results in cases where the poles become relocated in small steps, or in cases where the convergence stalls prematurely.

2.2 Fast Implementation

Even if the device under study has a moderate amount of ports, the size of the corresponding least-squares (LS) matrices may become prohibitively large. It was shown in [14] that these matrices have a sparse structure, and contain a lot of redundant information that can be discarded by the Vector Fitting algorithm. An efficient implementation which is based on the QR decomposition was applied to extract the essential information about the poles from each matrix element individually. This information is then considered at once to determine a common pole set for the entire transfer matrix. Significant savings in terms of computation time and memory consumption are obtained. The proposed algorithm, called Fast Relaxed Vector Fitting (vectfit3.m), is made available as MATLAB code on the Vector Fitting website [15].

3 Example : 48-port BGA Package

The fast fitting technique is used to compute a macromodel of a 48-port ball grid array (BGA) package, based on electromagnetic (EM) simulations. The top view of the structure is shown in Figure 1(a), and the package structure is shown in Figure 1(b). The BGA package is simulated with Agilent's Momentum RF EM simulator over a frequency range from DC up to 10 GHz, using 21 equidistant frequency samples. The rational function approximation is chosen to be proper, and the number of common poles is set to 8. All timing results are computed in MATLAB on a Pentium 4 Dual Core laptop computer with 2.4 GHz CPU clock frequency and 2 GB of RAM.

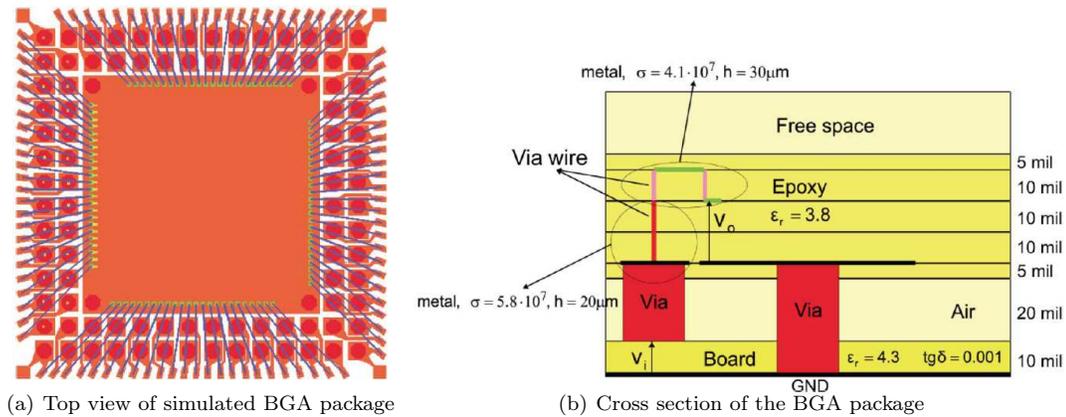


Figure 1: Simulated BGA Package

It is found that the standard vectfit.m implementation [15] is unable to perform the computations because the storage of the LS matrix requires a huge amount of memory resources. Fortunately, the MATLAB environment offers some sparse matrix data structures, which consume less computer memory by not storing the zero elements. The vectfit2.m routine [15] exploits these features, and is able to compute an accurate macromodel in 48.6 seconds using only 3 iterations. The maximum absolute error over all 1176 matrix elements is bounded by -67 dB, which is quite satisfactory. The fast vectfit3.m routine, as described in [14] is able to compute a macromodel with the same accuracy in only 0.82 seconds using the same number of iterations. This indicates that the overall macromodeling time is reduced by a factor of 60. Figure 2 shows a subset of the matrix elements, which confirms that an excellent agreement is observed between the 21 frequency samples (marked with dots), and the response of the macromodel (solid line).

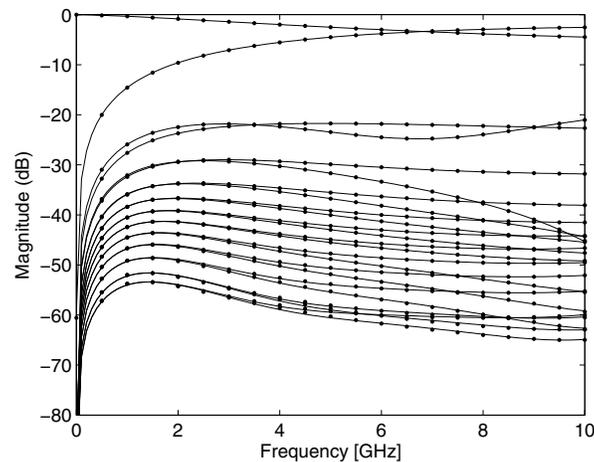


Figure 2: Magnitude of scattering matrix elements (subset)

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