Adaptive Frequency Sampling Algorithm for Fast and Accurate S-parameter Modeling of General Planar Structures

Tom Dhaene[1], Jan Ureel[2], Niels Faché[1] and Daniël De Zutter[2]

[1]HP-Belgium, Lammerstraat 20, 9000 Ghent, Belgium
[2]INTEC, University of Ghent, Sint-Pietersnieuwstraat 41, 9000 Ghent, Begium

ABSTRACT

A new adaptive technique is proposed to represent the spectral response of general planar structures over some frequency range of interest with a minimal number of frequency samples. Rational fitting functions are used to model and interpolate the S-parameters obtained through electromagnetic simulation.

The adaptive algorithm doesn't require any a priori knowledge of the dynamics of the S-parameters in order to select an appropriate sampling distribution. This greatly improves the transparent use of any electromagnetic simulator.

Keywords: adaptive frequency sampling, fitting technique, electromagnetic simulation.

1. INTRODUCTION

The combination of oversampling and straight line interpolation is a standard (but inefficient) approach used in circuit simulators and electromagnetic simulators to simulate and represent the circuit parameters of any device over a frequency range of interest. However, oversampling implies a waste of resources [1]-[2].

The electromagnetic simulation of complex structures takes so long that the user often reduces the number of sample points in order to get the results in a moderate time. If the sampling rate is reduced, many important features such as coupling effects and resonances may be missed (undersampling). Even if most of the desired frequency range is oversampled some important features could still be missed. So, traditionally some a priori knowledge of the dynamics of the circuit parameters is required in order to select an appropriate sampling distribution for the spectral response of a general planar structure.

In this paper, a new sampling scheme is presented. The 'Adaptive Frequency Sampling' algorithm (AFS) selects the frequency samples automatically in consecutive iterations and interpolates all S-parameter data using rational fitting models. This algorithm allows important details to be modeled by sampling the response of the structure more densely where the S parameters are changing more rapidly. It tries to minimize the total number of samples needed and to maximize the information provided by each new sample.

This tool will help the novice user to discover the fascinating world of electromagnetic simulators as accurate full-wave simulations can be obtained much faster without any a priori knowledge of the structure.

2. THEORY

All S-parameters of a general planar structure are represented by rational fitting models based on a limited number of samples. The 'Model Based Parameter Estimation' technique (MBPE) [3] is used to fit a physics based model (pole-zero behavior) to the S-parameters. The MBPE technique can be seen as a 'Frequency Domain Prony Method' (FDPM). The S-parameter fitting model is given by:

$$S(f) = \frac{N_0 + N_1 f + \ldots + N_n f^n}{1 + D_1 f + \ldots + D_d f^d} \quad (1)$$

$$S(f) \left(1 + \sum_{i=1}^{d} D_i f^i\right) = \sum_{i=0}^{n} N_i f^i \quad (2)$$

where n is the order of the numerator, and d is the order of the denominator. A least square fit is used to calculate the coefficients of the rational transfer functions. These simple and compact rational fitting models are used for fast frequency interpolation.

The S-parameters S(f) of the planar structures are calculated with the electromagnetic simulator HP-Momentum [4]. This full wave simulator can handle strips, slots as well as via's. It is based on the MPIE formulation [5].

The flow chart of the adaptive frequency sampling algorithm is shown in figure 1. The algorithm starts with two samples at the end frequencies. New samples are selected automatically. If the fitting error between the S-parameter models and the real data exceeds a certain limit, then extra sample points are added and new updated fitting models are calculated. This is repeated until convergence is reached. The location of new frequency samples is found by minimizing the maximum fitting errors of all S-parameters with respect to the frequency:

$$\text{MIN - MAX(fitting error)} \quad (3)$$

A reliable way to estimate the fitting errors is necessary. Different criterions can be used and combined. The difference between:

1. two d the real data and the rational fitting model,
2. two different fitting models which have a different numerator and denominator order, and/or
3. two models which use different data samples and/or use different frequency ranges

can indicate where the fitting error exceeds an acceptable threshold and consequently where one or more samples might be needed. The physical nature of the fitting models for the passive planar structures is also checked.

3. EXAMPLES

3.1. Semi-circular patch radiator

The reflection coefficient S_{11} of a field-coupled semi-circular patch radiator has been analyzed between 2 GHz and 4 GHz using the new adaptive frequency sampling algorithm and the commercial electromagnetic planar simulator HP Momentum [4]. The cross section and the top view (mesh) are shown in figure 2. The two semi-circular patches of different diameters are indirectly excited by the covered microstrip line. There are two resonance frequencies due to the different radius of the patch radiators. The AFS technique is used to locate the antenna resonances very fast as opposed to simulating the structure with a densely spaced set of frequencies.

The AFS algorithm automatically selects 11 sample points (in 10 consecutive iterations) and interpolates all data using rational fitting models. The fitting error is less than -70 dB. The simulation results correspond very well with earlier calculated results (2.75 GHz - 3.35 GHz) [6] as can be seen in figure 3. The automatically selected sample points are marked by small triangles. Note that the sampling rate is somewhat denser near the resonance frequencies of the structure. In figure 4 the simple straight line interpolation (40 samples) is compared to the new adaptive sampling simulation (11 samples). There is an important speed improvement (factor 4 to 5) due to the fact that far less sample points are required.

3.2. Microstrip lowpass filter

The cross section and the top view of the lowpass filter under study are shown in figure 5. An edge mesh is used for increased accuracy [4]. Note that the microstrip structure is quite long (as a function of the wavelength).

The AFS algorithm automatically selects 22 samples to model the reflection and the transmission coefficients of the planar structure in the frequency range: 0.1 Ghz - 20 GHz. The AFS simulations correspond very well with measurements (0.7 GHz - 20.05 GHz) as can be seen in figure 6. The AFS sample points are marked by small triangles.

4. REFERENCES

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5. FIGURES

1. Design planar structure and specify frequency range

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2. Perform electromagnetic analysis in new sample point(s)

↓

3. Build fitting model and estimate fitting error

↓

4. If (fitting error > maximum error):

   Determine frequency with maximum error and Repeat 2 & 3

↓

5. Stop

figure 1: Flow chart of Adaptive Frequency Sampling (AFS) algorithm.

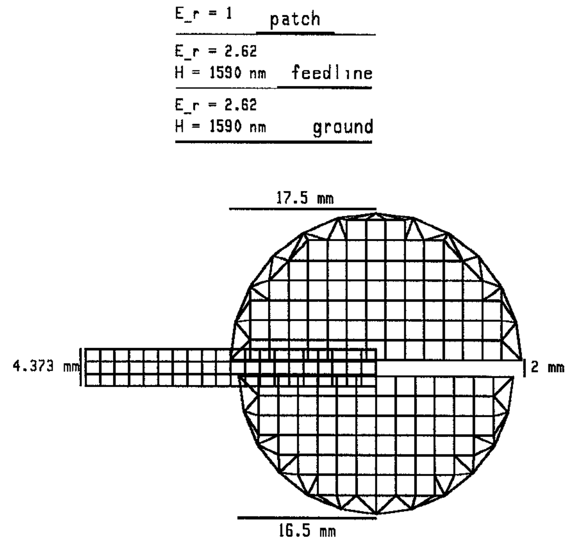

figure 2: Cross section and top view (mesh) of patch antenna.

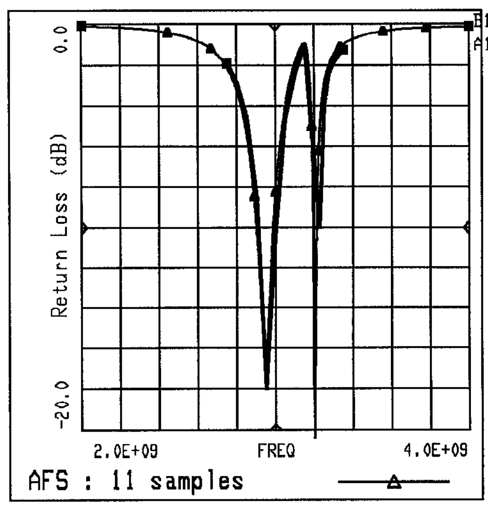

figure 3: Reflection coefficient S11 of patch antenna.
—Δ— : AFS simulation [2 - 4 GHz]
—— : reference paper [2.75 - 3.35 Ghz]

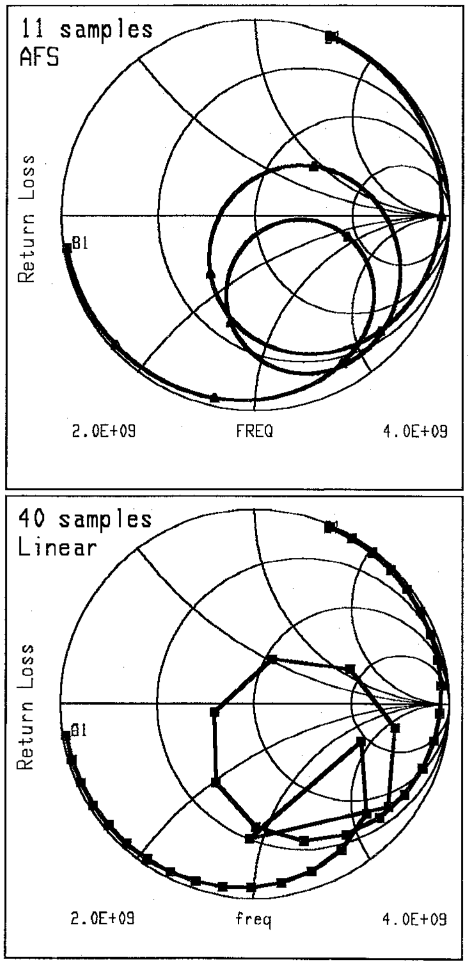

figure 4: Reflection coefficient S11 of patch antenna.
a) Adaptive Frequency Sampling: 11 samples
b) Straight Line interpolation: 40 samples
(AFS) algorithm.

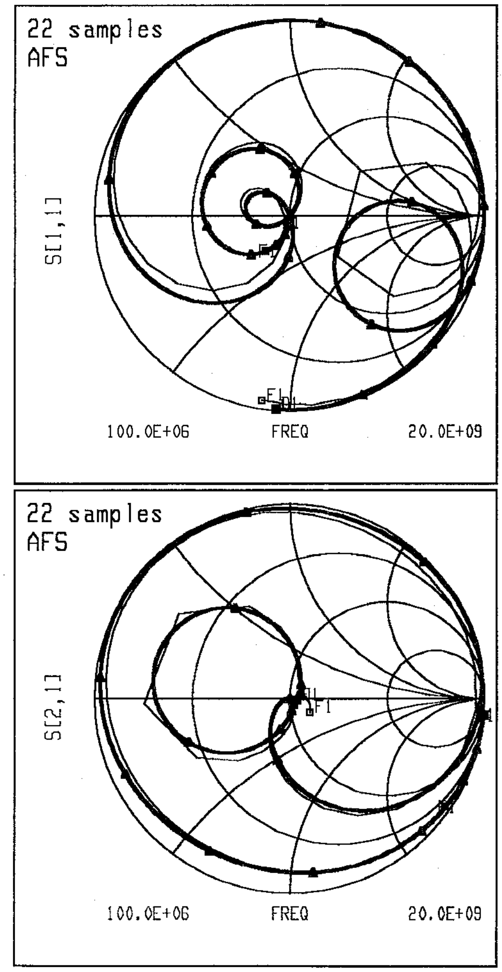

figure 6: Reflection and transmission coefficient of lowpass filter.
: AFS simulation [0.1 - 20 GHz]
: measurements [0.7 - 20.05 Ghz]

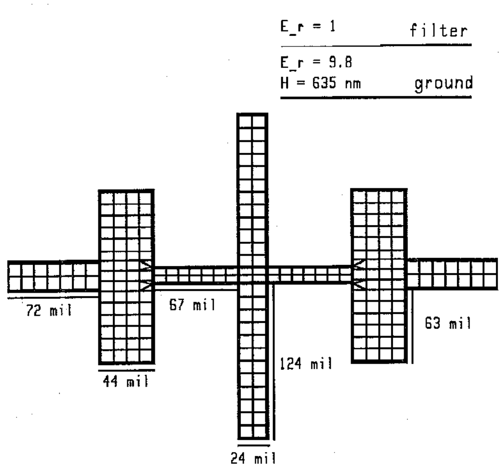

figure 5: Cross section and top view (mesh) of lowpass filter.