Application of Implicit Space Mapping in the Design of Hammerhead Filter in Millimeter-Wave Band

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Abstract: In this study, we present advances in microwave and millimeter-wave device modeling exploiting the Space Mapping (SM) technology. New SM-based modeling techniques are used that are easy to implement entirely in the Agilent ADS framework. The implicit space mapping algorithm is applied to the design of hammerhead filter in millimeter-wave band. The validity of this method is confirmed by comparison with full-wave EM simulation result and measured data. Based on the proposed method, a filter was designed and fabricated on a substrate with thickness of 0.254 mm and dielectric constant of 2.2. The experimental results show good agreement with simulated results. It is proved that the accuracy can be achieved using the implicit space mapping algorithm, and the design efficiency can be greatly improved.

Key words: Accuracy and high efficiency, hammerhead filter, implicit space mapping algorithm

INTRODUCTION

Filters play an important role in the successful operation of millimeter and submillimeter-wave mixers and frequency multipliers (Xue et al., 2003; Marsh et al., 2007; Maestrini and Ward, 2008; Zhang et al., 2011; Zhong et al., 2011a,b). Many simple filters can be designed with direct full-wave electromagnetic (EM) simulation optimization. However, occasionally it is necessary to achieve a larger bandwidth of operation and a greater level of stopband rejection which often involves the use of more complicated filter geometries which would spend so much time doing the direct EM optimization. The relative simplicity and flexibility of the implicit space mapping algorithm make it a particularly attractive tool for design of these more complex circuits.

The microstrip hammerhead filter has been an attractive candidate for use in wide stop-band mixer and frequency multiplier circuits since its introduction many years ago (MaMaster et al., 1976). Compared with the traditional low-and-high-impedance microstrip filter, the microstrip hammerhead filter is characterized by low-insertion loss, sharp rejection, shorter size and wider stop-band. These superior characteristics can be used to improve the performance of the mixer and multiplier in microwave and millimeter-wave band. However, complex structures, too much variables and absence of a simple and quick method for design have hindered its widespread use.

Electromagnetic (EM) simulation is accurate, but CPU intensive; hence, using a full-wave EM simulators such as Ansoft HFSS, or Agilent Momentum, in the hope of reducing CPU demand. Implicit Space Mapping (SM) technology (Bandler et al., 2004) addresses the issue of reducing the time-consuming full-wave Electromagnetic (EM) simulations of microwave structures with the help of a fast physics-based model or surrogate for device modeling and optimization. In the design of microstrip hammerhead filter, coarse models are realized in Agilent ADS. We use HFSS as the fine model evaluators. Agilent ADS schematics organize the ADS optimization engine and coarse and fine models to perform parameter extraction and surrogate optimization.

In this study, we adopt the simplified space mapping implementation in Agilent ADS, all the space mapping steps are integrated into ADS schematic. The processing of design for microstrip hammerhead filter was described.

Implicit space mapping algorithm: The formulation of the implicit space mapping algorithm is presented in (Bandler et al., 2004; Cheng et al., 2009).

A fine model optimal solution can be expressed as:

\[ x^* = \arg \min_{x} U(R_f(x)) \]  \hspace{1cm} (1)

where, \( R_f(x) \) is fine-model response vector, \( U \) is typically a minimax objective function with upper and lower specifications (Zhu et al., 2007), \( x \) is fine-model design parameters, and \( x^* \) is the optimal design to be determined.

In order to solve Eq. (1), the following iterative procedure is used by implicit space mapping:

\[ x^{k+1} = \arg \min_{x} U(R_f(x, p^k)) \]  \hspace{1cm} (2)
where, \( R_c(x, p) \) is a response vector of the coarse model with \( x \) and \( p \) being the design variables and preassigned parameters, respectively, \( R_c(x, p^0) \) is an implicit space mapping surrogate model with preassigned parameters \( p^0 \) obtained at iteration \( k \) using the parameter extraction procedure.

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p^k = \arg\min_p \left| R_f(x^k) - R_c(x^k, p^0) \right| \quad (3)
\]

In which we try to match the surrogate to the fine model. The initial surrogate model is \( R_c(x, p^0) \), where \( p^0 \) represents the initial preassigned parameter values. In other words, the surrogate model is the coarse model with updated values of the preassigned parameters. From the above derivation of the formulation of the implicit space mapping algorithm, we can find that our goal is to obtain the fine model optimal design without going to direct optimization of the fine model but instead using the surrogate model; i.e., the coarse model with updated values of the preassigned parameters. Parameter extraction and design optimization are performed solely on the surrogate model. A prediction of the next fine model design is also obtained through the surrogate.

**ADS schematic design framework:** We implement implicit space mapping optimization in the ADS schematic framework in an interactive way to greatly raise efficiency of microstrip hammerhead filter design. The space mapping implemented in 5 steps is as fellows:

**Step 1:** Set up and optimize the coarse model in ADS schematic

**Step 2:** Create the parameterized fine model in HFSS, the structure dimension is same as the value obtained in Step1

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**Fig. 1:** The structure of microstrip hammerhead filter.

**Fig. 2:** The coarse model in ADS
of the fine model and coarse model is very small; if

**Step 3:** Simulate the fine model and import the S parameter into ADS. Check the stopping criteria which are that the difference between responses satisfied, stop. Otherwise, optimize ADS coarse model to match fine model to perform parameter extraction

**Step 4:** Reoptimize the calibrated coarse model design parameters to predict the next fine model design

**Step 5:** Update the fine model design and go to Step 3

**Design of microstrip hammerhead filter:** Microstrip hammerhead filter with a Rogers 5880 substrate is shown in Fig. 1. Design parameters are \( x = [L_1, L_2, L_3, L_4, L_5, W_1, W_2, W_3]^T \) mm. Thickness of the substrate is \( H = 0.254 \) mm, dielectric constant is \( \varepsilon_r = 2.2 \), loss tangent is 0.0009, and the metallization is copper. The design specifications are \( |S_{11}| \leq -15 \) dB for DC \( \leq 15 \) GHz, and \( |S_{21}| \leq -25 \) dB for 35 GHz \( \leq 45 \) GHz.

Because the microstrip hammerhead filter works at high frequency, we use the scale model with scale factor of 5 to improve the accuracy of the coarse model in ADS. In this design, the fine model is simulated in Ansoft HFSS, the coarse model is constructed and optimized in Agilent ADS (Fig. 2).

The initial guess is \( x^{(0)} = [4.09, 2.52, 1.86, 0.81, 10.83, 1.66, 0.6, 1.13]^T \), the response of our initial tuning model and fine model is shown in Fig. 4a. One of the most important steps, parameter extraction, is implemented entirely in ADS (Fig. 3). We compensate the deviation between the tuning model and the fine model.
by calibrating the dielectric constant \( \varepsilon \), and the height \( H \) of the substrate as tuning parameters. We can see that the specification is not satisfied after the first iteration, but the parameter extraction using implicit SM yields a good match between the coarse and fine models (Fig. 4b). The coarse model is then optimized in ADS with respect to the design parameter. The new design parameters are assigned to the fine model. The optimal values obtained are \( \mathbf{x}^* = [2.52, 3.55, 1.01, 1.18, 7.64, 0.9, 0.5, 0.5]' \) mm after three iterations. The responses of optimized tuning model and the corresponding fine model are shown in Fig. 5. Clearly, difference between responses of the fine model and coarse model is very small. After structure dimensions of the scale model are divided by the scale factor of 5, we can get the final microstrip hammerhead filter satisfying the design specifications, which will be fabricated in section 5.

**Filter measurement:** The hammerhead filter is fabricated using current microelectronics technology without any additional process, and the entire physical configuration of filter circuit is shown in Fig. 6a. The dimensions of microstrip hammerhead filter are as follows: \( L_1 = 0.5 \) mm, \( L_2 = 0.71 \) mm, \( L_3 = 0.2 \) mm, \( L_4 = 0.24 \) mm, \( L_5 = 1.53 \) mm, \( W_1 = 0.18 \) mm, \( W_2 = 0.1 \) mm, \( W_3 = 0.1 \) mm. The measured S-parameter is shown in Fig. 6b. The LPF with two hammerhead cells in series has a 25 GHz stopband from 25 to 50 GHz. This achieves above 100% (-10 dB) relative bandwidth. As can be seen from Fig. 6b, the insertion loss from DC to 20 GHz is less than 1.1 dB, and the return loss is better than 18 dB in the passband.

**CONCLUSION**

In this study we reviewed the implicit space mapping concept and adopt the simplified space mapping implementation in Agilent ADS, all the space mapping steps are integrated into one ADS schematic. A detailed and easy-to-follow design optimization procedure was provided and the Agilent ADS implementation of the algorithm was described. Implicit SM algorithm greatly improves the efficiency of the design of complex structure. It will create favorable conditions for the widespread use of microstrip hammerhead filter in field of mixer and frequency multiplier.

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**REFERENCES**


