Accurate and Efficient Design of Double Post Substrate Integrated Waveguide Filters Using Simulators Based on Open Space Modal Expansions

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***Abstract*—An Agresive Space Mapping (ASM) strategy for efficiently and accurately designing passive filters in substrate integrated waveguide (SIW) technology is presented and successfully validated for the double post topology. Full-wave simulators based on open space modal expansions are used in both the coarse and fine models of this strategy.**

I. Introduction

The substrate integrated waveguide technology (SIW) is based on a synthesized waveguide in a planar dielectric substrate with two rows of metallic vias [1]. This low cost realization of the traditional waveguide circuit inherits the merits from both the microstrip for easy integration and the waveguide for low radiation loss.

In this work, a design procedure for filters with double post topology (see Fig. 1) is presented. However, this procedure is also valid for other topologies, such as off-centered posts, rectangular coupling windows, etc.

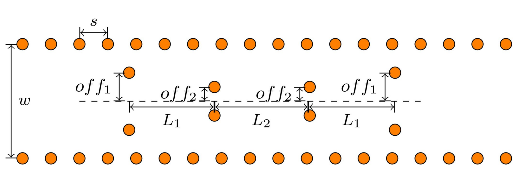

Fig. 1. SIW filter layout for the double post topology.

This design tool is based on an aggressive space mapping (ASM) strategy [2] with a very efficient simulation tool for the analysis of cylindric posts in H-plane rectangular waveguide devices in the coarse optimization space, and a very efficient and accurate SIW analysis tool in the validation space. Both tools are based on open space modal expansions.

II. SIW intrinsic parameters

As long as radiation losses in the SIW structure are negligible, the two rows of via holes of the side walls of the SIW (separated a distance equal to w) can be substituted by authentic metallic walls separated a distance a_{eq} in the equivalent rectangular waveguide. Both parameters and others, such as the repetition period of the via holes s or their diameter d, can be determined as in [3].

All these parameters must be calculated just once, at the beginning of the design process. Then, just the cavity lengths, L_i, and the post separation to the center, off_i (see Fig. 1), have been chosen as design parameters.

III. Aggressive Space Mapping (ASM)

In addition to classical approaches based on local or global optimization methods, the space-mapping (SM) technique [4] can be used in order to reduce the computational cost of the design procedure by combining two simulation tools: an efficient but badly accurate one (coarse model) that will be used in the optimization space (OS), and a highly accurate but inefficient tool (fine model) used in the validation space (VS). In this work, the design process is based on an ASM strategy [2], an improvement of the original SM technique which further reduces the number of fine EM evaluations.

A. Coarse model in waveguide technology

It has been demonstrated that attenuation and dispersion characteristics in SIW are almost identical to its equivalent rectangular waveguide [5]. Thanks to it, in this ASM strategy, an accurate and efficient analysis technique [6] for H-plane devices in rectangular waveguide with metallic or dielectric cylindric posts is going to be used as coarse model in the optimization space. It solves the matching between cylindrical and guided waves and uses the concept of transfer function or characterization matrix of a scattering object.

B. Fine model in SIW technology

A novel simulation tool for the efficient analysis of SIW devices with multiple accessing ports [7] is used as fine model in the validation space. In this method, fields inciding or emerging from each metallic via are expanded as cylindrical open space modes, and guided fields in the accessing ports are expressed as summations of progressive and regressive guided modes. All the integrals can be solved either analytically or by using the fast Fourier transform, thus making this new formulation highly efficient, and the computational cost does not increase when losses are considered in the analysis.

C. Initial point for x^*_{os} and parameter extraction

The first step in every ASM strategy is to obtain the optimum design which fulfills the specifications in the coarse model, x^*_{os} [2]. A synthesis methodology based on a prototype with inverters and transmission lines [8] has been applied, obtaining an initial point for it, x_{os}^{ini}, for an optimization process with the Nelder-Mead simplex algorithm [9].

Later, in order to obtain the $x_{os}^{(j)}$ in each ASM iteration [2], we have also used the Nelder-Mead simplex algorithm, first over the linear S_{11} response and then over the S_{11} in dB.

IV. Results

A. Filter specifications

In this work, we aim to achieve a passband filter with double post topology (see Fig. 1) for spatial applications in the C band, whose ideal transfer function is the standard four pole Chebyshev response, centered in 7 GHz and 3% of bandwidth. The return losses in the bandpass must be under 25 dB.

The filter has been implemented with a substrate Rogers $RO4003C^{TM}$ ($\varepsilon_r = 3.55$, $h = 1.524$ mm, $\tan\delta = 0.0027$, $t = 35$ μm). For these specifications, $d = 3$ mm, $s = 5.4$ mm and $w = 20.5674$ mm fulfill the design restrictions (Sec.II).

B. Design process and filter results

Table I shows the values of the design parameters in the different steps of the ASM process and Fig. 2 shows the comparison between their responses in their respective fine or coarse spaces. The computational cost for obtaining the optimum design for the coarse model, x_{os}^*, from x_{os}^{ini}, for 150 frequency points, has been 28min[1]. Then two ASM iterations have been necessary to arrive to the final x_{em} (i.e. the final 4-pole SIW filter design). The total ASM process has taken 34 min 29 s, and the number of simulations with the coarse model has been 460 and just 3 with the fine model.

TABLE I
EVOLUTION OF THE DESIGN PARAMETERS (mm)

	L_1	L_2	off_1	off_2	off_3
x_{os}^{ini}	13.7518	15.2384	5.9340	4.4403	4.1919
$x_{os}^* = x_{em}^{(0)}$	13.7624	15.2548	5.9791	4.4547	4.2036
1^{st} ASM, $x_{em}^{(1)}$	13.7165	15.2368	6.0005	4.4487	4.2159
2^{nd} ASM, $x_{em}^{(2)}$	13.6223	15.2128	6.0498	4.4929	4.2235

And finally, Fig. 3 shows the comparison between S-parameters of the complete filter simulated with losses and with taper transitions and the measured data.

V. Conclusion

A new design procedure for the efficient and accurate design of SIW filters with double post topology has been presented and tested with the design, fabrication and measurement of one bandpass filter structure.

It is based on an ASM strategy. The coarse model in the optimization space uses a very efficient simulation tool for cylindric posts in rectangular waveguide. The fine model, used just once in each ASM iteration, utilizes a novel and efficient analysis technique for SIW devices.

[1] Intel Core i5-760 (8M Cache, 2.80 GHz) processor.

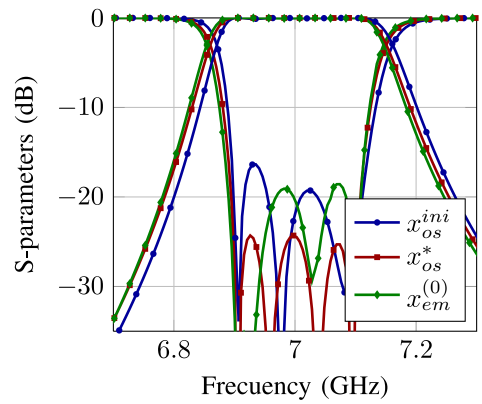

Fig. 2. Response in the different steps of the ASM process.

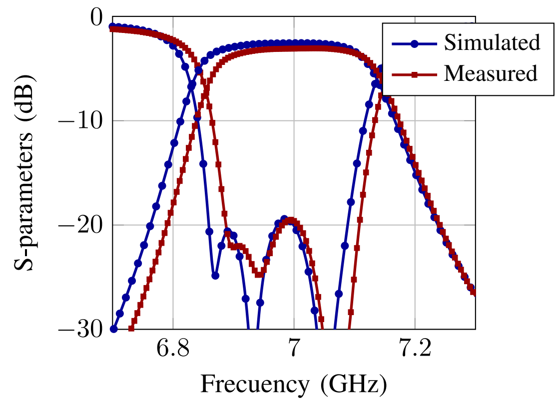

Fig. 3. Comparison between simulation with losses and measured data.

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