Simple tuning procedure for coupled-resonator filters.

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A new method for the initial design of direct-coupled cascaded resonators waveguide filters is proposed. The method is based on tuning the resonant frequency of cascaded resonators separately and is equally valid for the uniform and non-uniform case. The initial values obtained are in many cases better approximation than equivalent K-inverter resonator prototypes, and the whole design procedure requires significantly less computational effort. Furthermore the method can predict the stopband performance of the filter from the harmonic behaviour of its resonators. Numerical and experimental results in the case of E-plane filters demonstrate the validity.

1 Introduction

Waveguide filters are commonly used in applications where high power handling capability or low insertion loss are important features. The design of such structures usually involves two steps. At the first step, initial values for the physical dimensions of the structure are assigned. Then usually a final optimisation of the filter's dimensions is required, in order to satisfy the filter's specifications.

The tuning process for high performance filters consisting of many resonators is time consuming and expensive [1]. The computational effort for the filter optimisation highly depends on the number of variables involved, the cost of each evaluation of the objective function and how good approximation of the desired values the initial values are. The cost of an evaluation of the objective function is rapidly increasing when the propagation characteristics can not be computed from closed-form expressions and the analysis demands full-wave numerical methods. Therefore, it is major concern to keep the number of variables involved in the optimisation limited [2]. For a filter of the n^{th} order this number is typically of the order of $k \cdot n$, where k is the number of variables that determine the physical layout of a resonator.

This contributions therefore proposes a new method for the initial design of direct-coupled waveguide filters consisting of cascaded resonators, that involves a limited number of actual physical parameters at each step. The procedure is computationally efficient and rapidly convergent to a good approximation of desired filter performance. Furthermore, it gives at the first step of the design a guiding tool for the stopband performance of a filter by the harmonic behaviour of its resonators.

2 Method

In order to demonstrate the proposed method, E-plane filters were chosen as an example. For the design of uniform E-plane filters (Fig. 1 where s_i =b), a filter circuit with impedance inverters and series half-wavelength resonators is used as prototype [3]. The waveguide section between two subsequent metal septa form a resonator and subsequent resonators are coupled through K-inverters, realised by the metal septa. The design procedure proposed by [4] gives very good initial values for the uniform case, hence the final optimisation is a relatively easy computational task, and in many practical cases is not needed at all [5].

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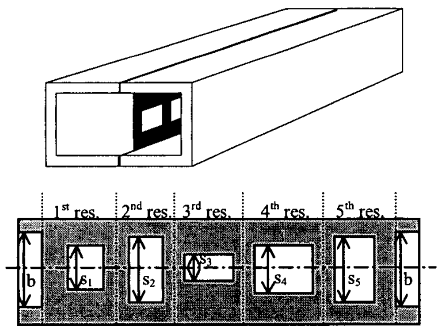

Fig. 1: Layout of ridge waveguide filter (non-uniform case)

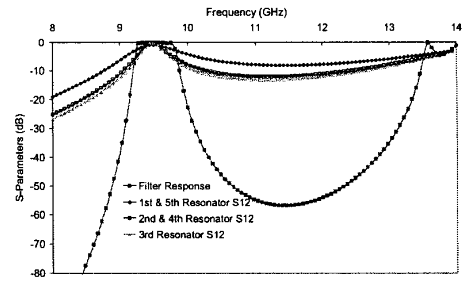

Fig. 2: Superposition of filter [2] and resonators response

In the non-uniform case, ridge waveguide is introduced in the resonators of the filter. This technique is known to improve the stopband performance of the filter [6]. A common analysis involves application of numerical method (ie. transverse resonance technique), since the propagation characteristics can not be derived by closed form expressions. The design is further complicated by the fact that the wave impedance at the input port (rectangular waveguide) differ from those in the resonator sections (ridge waveguide). Greater are the complications encountered in the case where subsequent resonators have different ridge's gap dimension and hence different propagation characteristics. When the design procedure [4] is applied for such cases, the initial values obtained are a worst approximation of the desired values and therefore the optimisation procedure needs extended computational effort.

The proposed method, instead of half-wavelength resonators coupled through K-inverters, assumes that midway each metal septum until midway the following one resonator is formed (with an exception for the first and last resonator). The filter then consists of a cascade of such resonators (Fig. 1). Each resonator can be characterised by 2 or 3 physical distances, namely the septa lengths and the line length, depending on whether is a symmetrical or non-symmetrical resonator. Fig. 2 shows a superposition of the response of a ridge waveguide filter published in [6] and the 3 cascaded resonators of which it consists. The resonant frequencies for the cascaded resonators coincide, and the variation of the quality factor Q is responsible for the filter behaviour.

This observation gives a tool for the initial design of non-uniform waveguide filters. The filter behaviour can be reproduced substituting any resonator with a new, say ridged, as long as the new resonance behaviour matches the behaviour of the corresponding resonator of the initial filter. Similarly, all resonators can be substituted by new, and this procedure leads to the initial design of a new filter. For a filter of the nth order, n resonators need to be optimised, characterised by 2/3 (symmetrical/non-symmetrical) variables each. This procedure gives good initial dimensions for the filter. It partly transfers one optimisation in 2n+1 dimensions to n optimisation procedures at 2 or 3 dimensions. The final optimisation is then limited to a significantly reduced area of the 2n+1 dimensional space.

3 Numerical and Experimental results

Fig. 3 shows the superposition of the three resonators of a prototype conventional E-plane filter with ridged waveguide resonators of different gap sizes. Note that while the first-order resonance is identical, ridge waveguide resonators exhibit harmonic resonance shifted towards higher frequencies compared with the initial resonators, thus improving the stopband performance of the new filter. Cascading the new resonators by adding the lengths of cascaded septa, yields the response shown on Fig. 4. Even though the produced response is not optimum, it is a good starting point for a final optimisation. As it is expected, the spurious harmonic passband of the filter is shifted towards higher frequencies, following the pattern of its resonators.

Fig. 5 shows the first and harmonic resonance for ridge waveguide resonators of different gap. It is evident that while the first-order resonance behaviour is identical (a fact that according to the above

make any of them equivalent element in a filter), the harmonic resonance is shifted towards higher frequencies for narrower gaps. This graph shows the stopband limitation of ridge waveguide filters and provides a guiding tool for the choice of the gaps' sizes during the design of filters with strict stopband specifications. For better stopband performance, the gap should be narrower, bearing always in mind the power handling capability and the increased number of modes needed [Zaki power].
In order to verify the accuracy of the simulator and the validity of the above results, Fig. 6 shows the response obtained after fabrication and measurement of the filter shown on Fig. 2. The simulated and experimental responses are in very good agreement.

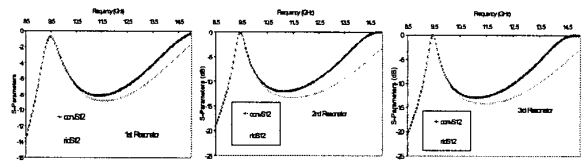

Fig. 3: The 3 different resonators of filter of Fig. 4

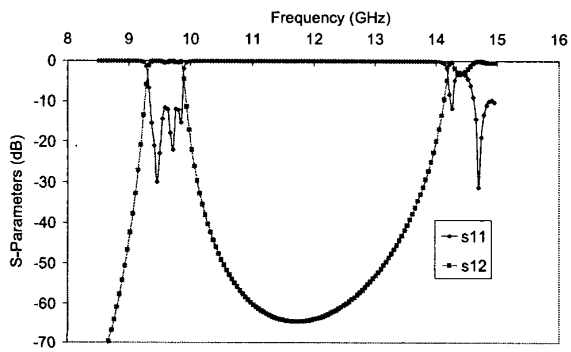

Fig. 4: The initial response for non-uniform 5-resonator E-plane filter

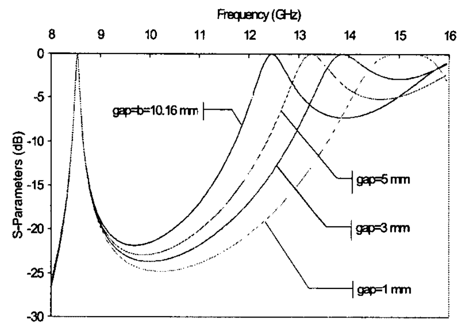

Fig. 5: First-order and harmonic behaviour for ridged resonators of different gap

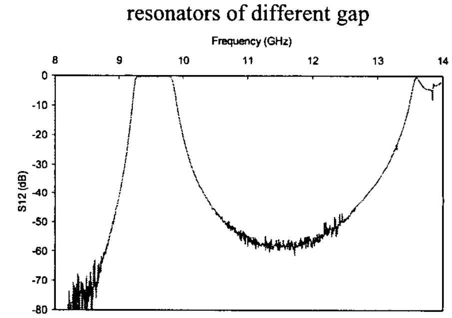

Fig. 6: Experimental measurement of filter shown on Fig. 2

4 Conclusion

A new procedure for the initial design of both uniform and non-uniform coupled-resonator waveguide filters has been developed. The new method involves partial optimisation of distinct resonators and reduces drastically the number of variables involved. Its validity was demonstrated for the case of a non-uniform waveguide E-plane filter. The developed method also predicts the stopband performance and provides a guiding tool for the design of filters with strict stopband specifications. Experimental evidence demonstrates the validity of the simulation tool

Acknowledgements

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