Accurate CAD of integrated band-pass and second harmonic band-reject microwave filters

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Abstract

In this paper we describe a procedure for the design of integrated band-pass and band-reject filters in rectangular waveguide. Following the procedure described, each resonant cavity produces one transmission and one rejection pole that can be positioned in frequency independently from each other. As a result, a band-reject transfer function of the same order of the pass-band filter can be implemented to eliminate the second harmonic of the filter without increasing the size of the hardware. In addition to theoretical results, measured data are also presented, indicating how the procedure described can be effectively used to manufacture microwave filters which exhibit substantial second harmonic suppression.

I Introduction

Microwave filters are generally designed to be compliant with a given set of electrical specifications. In general, both in-band and out-of-band (or rejection) specifications are given. The rejection specifications are normally divided into near-out-of-band and far-out-of-band specifications. The near-out-of-band and the in-band specifications are used as the basic guideline for the actual band-pass filter design. The far-out-of-band specifications are usually satisfied by adding an additional low-pass (or band-reject) filter which is designed to give the required rejection. In many applications, a far-out-of-band rejection specification is required in or near the second harmonic of the band-pass frequency.

In this paper we describe a CAD procedure which allows to *integrate* the design of the band-pass filter with the one of the second harmonic band-reject filter in a single microwave component thereby providing significant savings in hardware size and mass.

The integration of band-pass and band-reject is obtained by using the interactions with the higher order modes generated by the coupling windows. These interactions can, in fact, be exploited to generate, within a single cavity, both a transmission and a rejection pole which can be positioned independently in frequency. Although this possibility was indeed known [1], [2], no practical design procedure has been reported, to the author knowledge, which can be used to systematically design integrated band-pass and second harmonic band-reject structures.

In the remainder of this paper, we first discuss the basic implementation of transmission and rejection poles, we then discuss in detail the integrated filter design procedure and, finally, we present simulated and measured results for a practical application that fully validate the integrated band-pass and band-reject CAD procedure.

II Transmission poles and transmission zeros

The possibility of generating, within a single rectangular cavity, independent transmission and rejection poles by exploiting the interactions between the fundamental (even) $TE_{0,1}$ and the first higher order (odd) $TE_{0,2}$ mode has already been reported [1], [2]. The

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resulting structures, however, have one major drawback. They loose the structural simplicity, which is characteristic of inductively coupled filters.

Another more attractive possibility is to use the interaction between the fundamental $TE_{0,1}$ and the higher $TE_{0,3}$ mode. A destructive interference between these two modes is in fact possible because their modal patterns, as shown in Fig. 1, are out of phase in the center of the waveguide cross section.

The cavity structure that is required in order to exploit this possibility is shown in Fig. 2. The transmission pole is established by the standard resonant cavity behavior of the fundamental $TE_{0,1}$ mode. The input and output coupling strengths are controlled by the input and output apertures $a1$ and $a3$, respectively, while the resonant frequency is essentially controlled by the cavity length $l2$.

The centered apertures of the cavity, however, couple energy also into the next $TE_{0,3}$ higher order mode. This coupling can therefore provide the additional signal path that is required to produce a transmission zero. The location of the transmission zero produced can be controlled if the strength of the additional signal path can be controlled relative to the fundamental (resonant) signal path. This control can be easily achieved by changing the resonant cavity width $a2$.

As an example, we show in Fig. 3 the simulated insertion loss response of the structure shown in Fig. 2 where the relative cavity width a_2/a is changed from 1.12 to 1.69. The simulation, performed using the full-wave procedure described in [3], clearly shows that changing the resonator width has a very small effect on the resonator center frequency (at about 20 GHz) but produces a rejection pole which can be positioned within a 10 GHz band around the second harmonic of the resonator at 40 GHz.

This result clearly demonstrates that we have indeed two parameters, namely the cavity length and the cavity width, to control independently the frequency location of the transmission and rejection poles.

III CAD of Integrated band-pass and band-reject filter

The CAD procedure that we followed in order to obtain filters with integrated second harmonic rejection essentially consists of two iterations of the procedure discussed in [4]. The starting point is always the selection of an ideal Chebyshev transfer function that satisfies both the in-band and near-out-of-band specifications. Once the ideal transfer function has been selected, the first iteration of the CAD procedure can be completed thereby obtaining a waveguide structure that satisfies only the given in-band and near-out-of-band specifications. For this first iteration, the width of all resonators is kept constant and equal, for instance, to the width of the input/output waveguide.

Once the first iteration is completed, we know the total number of cavities which are required and, as a consequence, we also know the total number of rejection poles that we can implement. It is our experience that, in order to simplify the final hardware manufacture, it is best to set the first half of the rejection poles conveniently spaced to cover the complete rejection band required. The selection of the appropriate cavity widths to obtain this result can now be performed.

To proceed, we simulate again the first cavity only of the real waveguide structure and we adjust the cavity width of the first resonator to produce a rejection pole at the high end of the required second harmonic rejection band. We then add to the structure the second resonator and adjust its width in order to produce an additional rejection pole at an appropriate lower frequency location. This process is continued up to the center of symmetry of the filter, producing rejection poles up to the lower end of the desired rejection band.

At this point, all cavity widths have been dimensioned, and the complete filter can again be analyzed. The result of the simulation will now indicate that the structure obtained does indeed produce a rejection band at the desired location but has a degraded in-band response.

The second iteration of the procedure described in [4] can now be performed using as cavity widths the one selected in the previous step. The final result of the second iteration will now be a filter structure that is compliant with respect to the in-band and near-out-of-band specifications and that also exhibit a rejection band at the required out-of-band location.

In some cases, it may be required to perform one more iteration of the complete procedure in order to obtain perfectly compliant hardware. It is our experience, however, that two iterations are normally enough to obtain a satisfactory performance.

One limitation of the procedure just described is that while it is generally possible to design filters with a second harmonic rejection bandwidth approximately equal to the filter band-pass, nothing can be decided a priori with respect to the achieved rejection levels. The designer must therefore perform in each specific case a trade-off between the achievable rejection level and bandwidth.

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IV Measured results

The procedure described in the previous section was used to design a five pole microwave filter with a center frequency at 21.5 GHz and a 600 MHz bandwidth. Figure 4 shows the simulated results obtained at the end of the filter CAD procedure, including the required in-band and out-of-band specifications. As we can see, in addition to a compliant in-band performance, we have been able to obtain a rejection band at the desired frequency location with more than 30 dB of rejection level.

The filter structure was then manufactured and tested. The results obtained are shown in Fig. 5. As we can see, they are in very good agreement with the simulated results in Fig. 4.

V Conclusion

In this paper we have discussed a CAD procedure that allows for the integrated design of band-pass and second harmonic band-reject filters. The band-reject function is obtained via the interaction of the fundamental resonant mode within each filter cavity with the even higher order modes generated at the coupling apertures. Using this interaction, one rejection pole and one transmission pole can be implemented within each resonant cavity without increasing the size of the hardware. A filter design procedure is also discussed which allows for the CAD of the integrated band-pass and the band-reject functions. In addition to theoretical discussions, measured data are also presented which fully validate the proposed CAD procedure.

References

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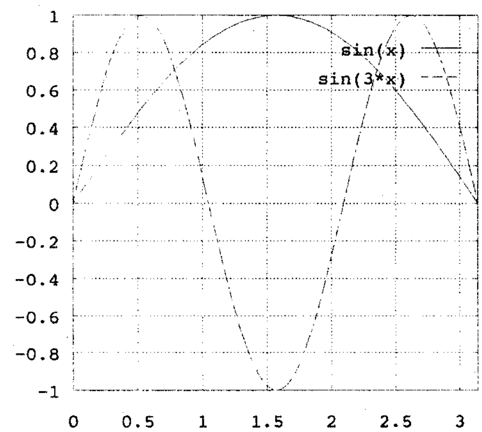

Fig. 1 Modal patterns of $TE_{0,1}$ and higher $TE_{0,3}$ modes .

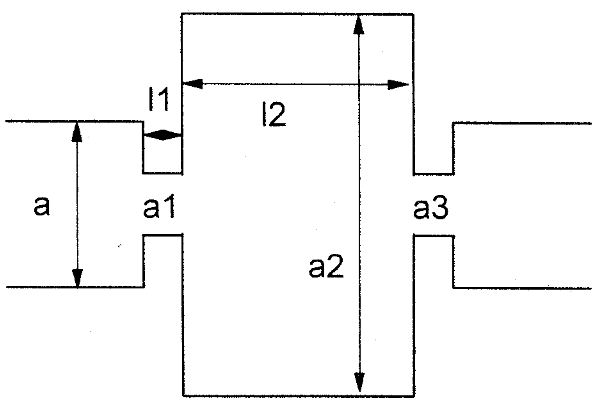

Fig. 2 Cavity structure used to exploit the interaction between $TE_{0,1}$ and $TE_{0,3}$ modes .

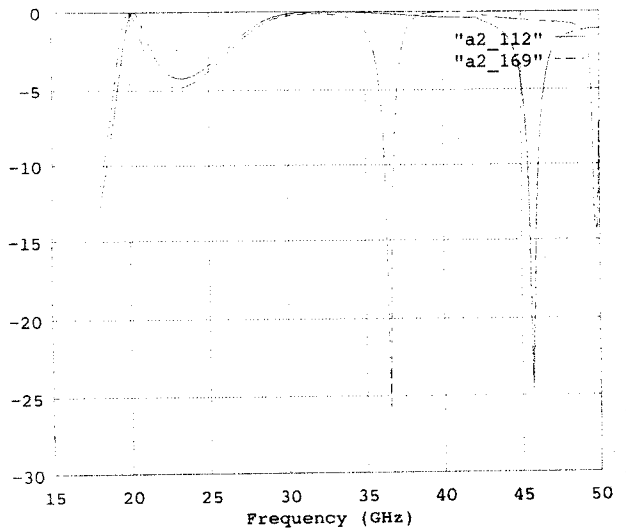

Fig. 3 Simulated response of the single cavity in Fig. 2 for two values of relative cavity width a_2/a.

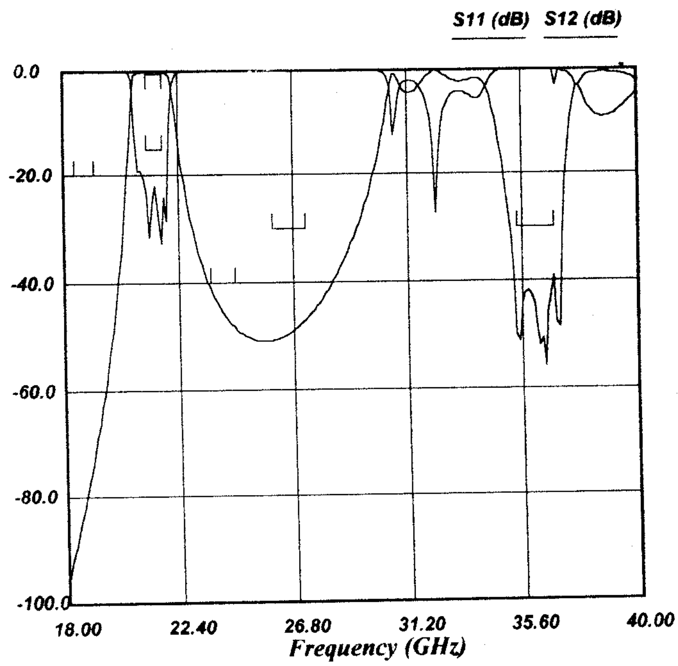

Fig. 4 Simulated response of a five pole band-pass filter with integrated second harmonic rejection.

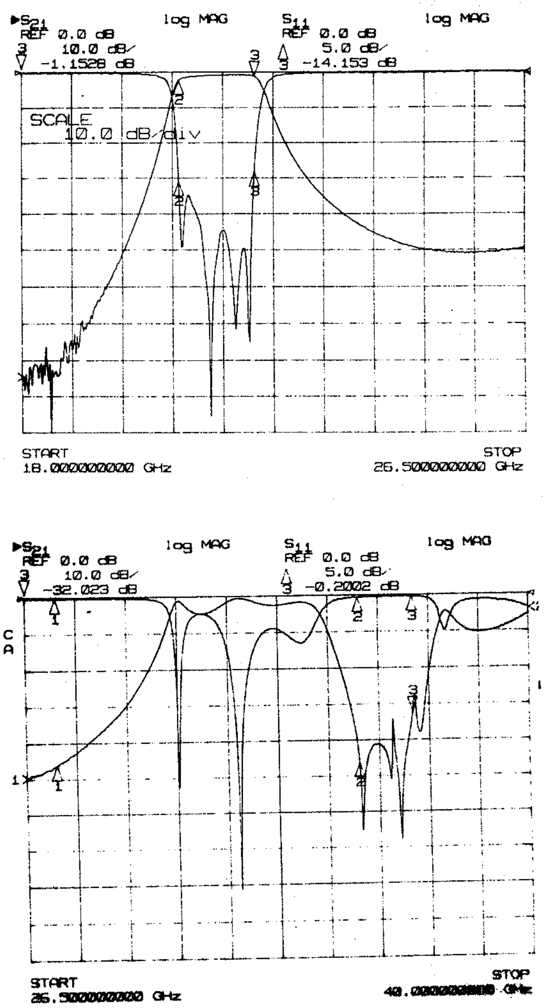

Fig. 5 Measured in-band and out of band response of the filter in Fig. 4.