PERIODIC STRUCTURES FOR ORIGINAL DESIGN OF VOLUMINOUS AND PLANAR MICROWAVE FILTERS

B. Lenoir, D. Baillargeat, S. Verdeyme, P. Guillon, C. Zanchi*, J. Puech*

IRCOM, Faculté des sciences de Limoges, 87060 Limoges Cedex, France

*CNES, 18 av Edouard Belin, 31401 Toulouse Cedex, France

ABSTRACT

The main objective of this paper is to demonstrate that periodic structure can be used to design filters at millimeter frequency band. Theoretical analyses are performed applying the Finite Element Method to design a volumic microwave filter at 35 GHz and a planar one at 6 GHz. Devices are built and tested at the IRCOM. Theoretical results are compared with success to experimental ones.

I. INTRODUCTION

Periodic structures are one, two, or three-dimensional periodic dielectric and/or metallic material that exhibit frequency regions in which electromagnetic waves cannot propagate [1]. For a few years, it has been proved that periodic structures have one interesting characteristic in microwave and millimeter wave domains [2]-[3]-[4].

In this paper, we would like to prove the faisability of microwave filter and millimeter frequency band filters using these periodic structures. We introduce rigorous design of two bandpass filters applying the three-dimensional Finite Element Method (FEM).

All theoretical analysis are performed applying a finite element software (FEM) developed in our laboratory. This software solve the Maxwell's equation in the frequency domain, and permits to establish the scattering [S] matrix, unloaded Qu, resonant frequency... applying free or forced running. Our software has already been explained in several papers [5],[6], and our purpose is not to describe it here.

In the first part, we present a three-pole waveguide filter around 35 GHz using dielectric periodic structures.

In the second part of this paper, a global analysis is performed to characterize a planar structure as microstrip lines on original periodic etching in the ground plane. This study permits to realize a two-pole filter and to reduce the second harmonic influence.

Devices are built and tested. Comparisons between theoretical and experimental results permit to validate filtering objectives of the devices under consideration

II. WAVEGUIDE FILTER USING DIELECTRIC PERIODIC STRUCTURES

The purpose of this part is to design and realize an original waveguide 3-pole filter with dielectric insert around 35 GHz. Usually waveguide E-plane filters are proposed with all-metal insert [7]. Metal inserts correspond to evanescent domain and air to propagate domain. But, such filters present mechanical problems depending on mechanical tolerances, and for high input microwave power, breakdowns can appear leading to irreversible damages. That's why we propose to use dielectric inserts in place of metal inserts (figure 1). Indeed, we hope to obtain better mechanical tolerances and to suppress microwave breakdown.

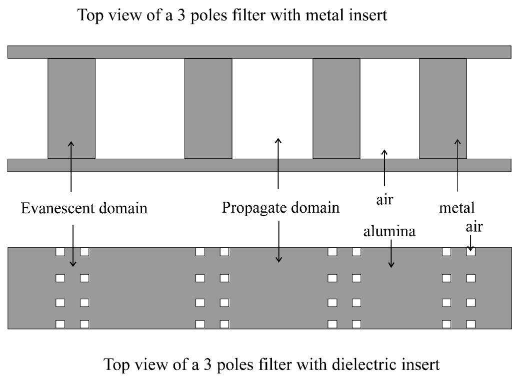

Figure 1: Comparison between 3-pole filters with metal inserts/ dielectric inserts

To realize the same function than metal inserts, dielectric inserts must be evanescent. So, to obtain evanescent domain using dielectric inserts, we create periodic holes in alumina (εr=9.8) substrate (figure 2), in order to obtain a frequency band gap. Substrate thickness is equal to 0.635mm. As it is well known, periodic structures disturb the propagation of the electromagnetic wave, and a frequency band-gap is obtained between 31 and 44 GHz as we can observe in figure 3 [4].

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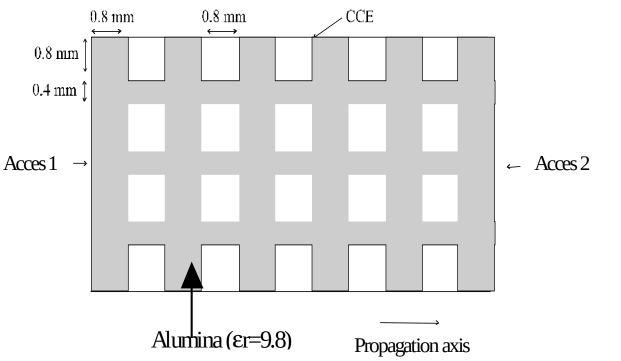


Figure 2: Dielectric structure with periodic holes

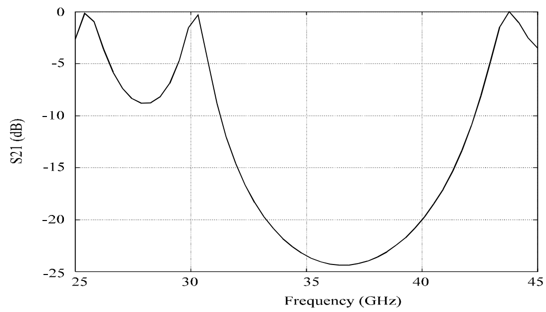


Figure 3: Theoretical band gap

Applying a classical synthesis method [8], based on the reflection coefficients values at each interface between evanescent and propagate domain, we define the 3-pole filter dimensions described in figure 4, and the transition dimensions between the 3-pole filter and the standard waveguide (figure 5).

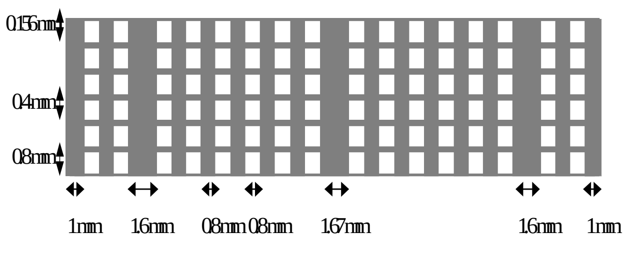


Figure 4: Design of the 3-pole filter with dielectric insert

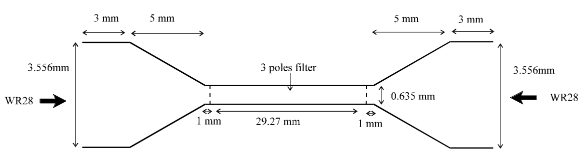
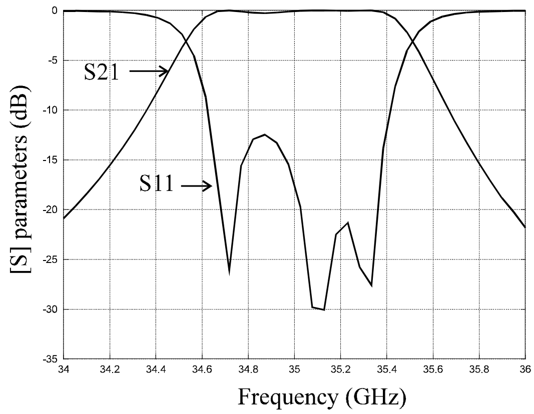


Figure 5: Cross section of the 3 pole filter with the excitation

Then, number of holes along propagation axis in evanescent domain and their dimensions, the length of the propagating domain and the transition dimensions have been optimized applying the FEM to obtain good filtering



objectives. Figure 6 present the theoretical filter response. In that case the dielectric and metallic losses are not taken into account. The central frequency of this response is equal to 35.1 GHz and the bandwidth at –3 dB is equal to 1 GHz (2.9% around 35.1GHz).

Figure 6: Response of the theoretical 3 pole filter

The realization of the 96 holes in the alumina dielectric substrate have been made at the University of Bordeaux I (France), using a femtolaser and the mechanical precision of each hole is around ±10 µm. The picture of the experimental 3-pole filter is presented figure 7.

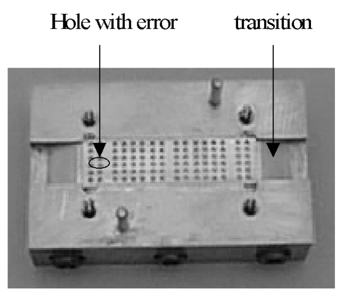


Figure 7: Picture of the 3-pole filter with the transition

An HP8510C network analyzer is used to measure both the transmitted and reflected waves. Theoretical and experimental results are presented figure 8. We obtain nearly the same results concerning the central frequency (1% of error) and the bandwidth at –3 dB (7.5 % of error).

Experimental losses are equal to –2.7 dB taking into account the transition ones equal to –0.6 dB. Furthermore, S11 and S22 parameters are not the same, because one of the 96 holes is shifted about 100 μm along the propagation axis. However, we have demonstrated the realization of such device and an another experimental 3-pole filter is about to be designed.

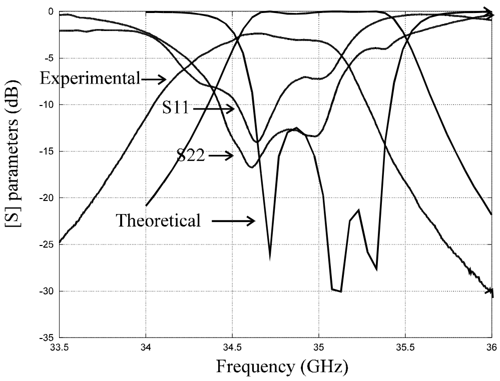


Figure 8: Theoretical and experimental responses of the 3-pole filter with dielectric insert

III. PLANAR FILTER USING ORIGINAL ETCHING IN THE GROUND PLANE [9], [10]

In the second part of this paper, an original structure is proposed to realize a compact planar 2-pole filter with periodic etching in the ground plane which permit to eliminate the second harmonic influence. The proposed coupled lines filter is composed of an alumina dielectric substrate enclosed in a metallic box. On the upper face of the substrate two excitation microstrip lines coupled to a $\lambda/2$ microstrip resonator are designed. On the ground plane of the substrate we design three periodic etching to eliminate the second harmonic, and one of this etching has an original geometry to realize a defect in the ground plane to create a transmission level. Dimensions of periodic etches are chosen in order to have a frequency band gap between 9 and 15 GHz to reduce the second harmonic influence. Then with the low frequency of the band gap, we can obtain a filter with a very high rejection at the upper side of the filter response. As we can see in figure 9, the proposed two-pole filter is more compact than a classical one. In fact, its dimensions are nearly the same than the ones of a classical one-pole filter. So compact size is one of the main advantages of the proposed two-pole filter.

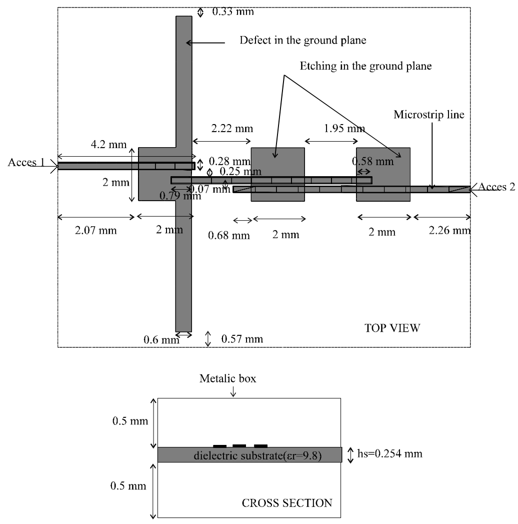


Figure 9: Design of the 2-pole filter

The dimensions of the 2-pole filter are optimized applying the FEM to satisfy the filtering patterns. Figure 10 present the theoretical response of this original 2-pole filter.

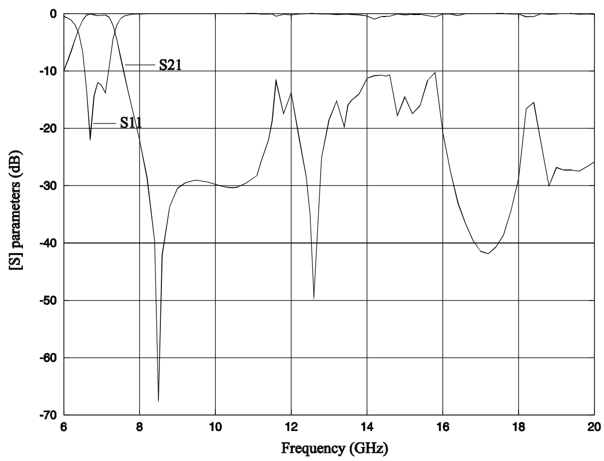


Figure 10: Theoretical [S] parameters of the 2-pole filter

The central frequency of this response is equal to 7 GHz and the bandwidth filter at –3 dB is equal to 1 GHz. Furthermore, we can see that the influence of the second harmonic is reduce, thanks to the three ground plane etches.

An HP8510C network analyzer is used to measure [S] parameters. So, figure 11 present experimental results of the original 2-pole filter, and figure 12 the comparison between experimental and theoretical results of the 2-pole filter.

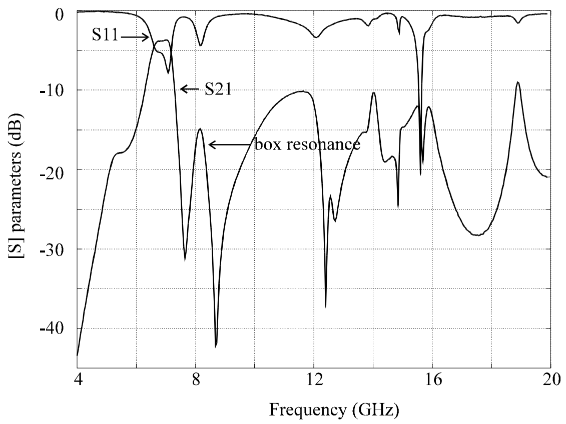


Figure 11: Experimental results of the 2-pole filter

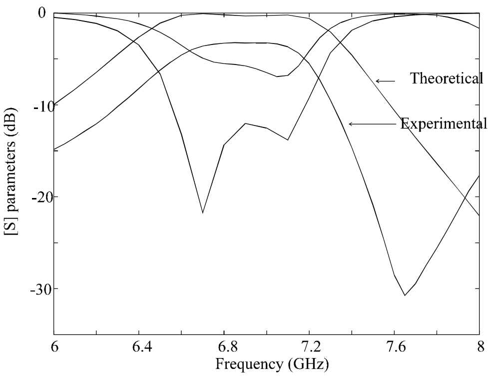


Figure 12: Comparison between experimental and theoretical results of the 2-pole filter

We can see that experimental results are in good agreement with theoretical ones. A two-pole filter response is obtained around 7 GHz and the bandwidth at –3 dB is equal to 700 MHz. We can observe that a parasitic resonance depending to the box dimensions appears at 8 GHz. The harmonic contribution is really attenuated by the band gap. We can note the high rejection at the upper side of the filter response due to the localization of the band gap.

IV. Conclusion

In this paper, we designed two bandpass filters using periodic structure. All the theoretical results are in good agreement with experimental ones. We have demonstrated the possibility to realize waveguide filters with dielectric inserts in the millimeter frequency band. Then, a planar filter composed of a classical microstrip resonator on a PBG substrate is designed. This filter present smaller size than classical one and its original topology permits to reduce the second harmonic contribution. So, different applications of periodic structures have been proposed to define waveguide filters, or planar ones. As we have shown for the planar filter, periodic structures can be used to improve classical filter behavior and to design very compact filter.

Acknowledgement

The authors wish to acknowledge the PALA loboratory of Bordeaux University for the waveguide realization.

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