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Comparative study of filters based on periodic structures in SIW technology

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***Abstract*—In this work, the study of two different topologies of S-band band-pass filters based on periodic structures in substrate integrated waveguide (SIW) technology is theoretical and experimentally addressed. The first topology consists of periodic rectangular perforations of the SIW substrate. In this filter topology, the lower cutoff frequency is determined by the cutoff frequency of the first Floquet mode of the periodic structure, while the upper cutoff frequency and the rejection band are conditioned by its first band-gap. The second topology consists of a periodic array of square complementary split-ring resonators (CSRRs) etched on the waveguide surface. In this case, the use of subwavelength resonators with evanescent-wave transmission leads to a much smaller filter, given that the pass-band is below the cutoff frequency of the waveguide. The effect of the different dimensions of the unit cell in the filters characteristics (lower cutoff frequency, pass-band, and rejection-band associated to the first band-gap of the periodic structure) is analyzed through the dispersion diagram of the periodic cell. A band-pass filter based on each topology has been designed and built, showing in both cases good matching and low insertion loss in the pass-band, and a deep rejection band.**

I. Introduction

Periodic structures show very attractive filtering properties in the frequency domain associated with the appearance of permitted and forbidden frequency bands in their dispersion diagram, yielding a size reduction on the one hand, and an improvement of the rejection band on the other hand, and most importantly, robustness against manufacturing intolerances. There are many examples of periodic structures with filtering applications [1]– [6]. In recent years, many works have been published on the Substrate Integrated Waveguide (SIW) [7], [8]. In the field of filtering design, SIW structures have been adopted in a great variety of filter topologies [9]– [11]. Recently, a new filter typology based on perforations of the dielectric substrate has been developed [12]– [14], adding flexibility to the designs and extending this concept to half-mode and folded structures. There have been also many works published on

In this work, Electromagnetic Band-Gap (EBG) structures in SIW technology are applied to the analysis, design and comparison of two band-pass filters in S-band with different types of periodic cell, in order to highlight their advantages and disadvantages. The first filter is based on the realization of periodic rectangular perforations of the dielectric substrate of the SIW, which has originally been proposed in C-band [15]. In the second periodic SIW filter, square complementary split-ring resonators (CSRRs) [16]– [19] are periodically etched on the waveguide surface. In Sec. II the analysis of the dispersion diagram of the unit cell of each periodic structure is carried out, showing the dependence of the width and location of the first pass-band and stop-band on the different parameters of the periodic cell. Next, in Sec. III two periodic filters are presented based on each unit cell topology, highlighting their differences in terms of size and electrical response. Finally, the conclusions of the work are summarized in Sec. IV.

II. Dispersion characteristics of the periodic SIWs under study

In this section, the dispersion characteristics of two different types of periodic SIWs are analyzed.

A. *SIW with periodic rectangular perforations of the substrate*

The first configuration of periodic SIW studied has been obtained by periodically perforating the substrate with rectangular profile perforations, and whose unit cell is shown in Fig. 1. The waveguide of period D is characterized by its width a_{siw}, and height b, corresponding to the height of the substrate employed, which in our case has been Taconic RF-10 (with relative permittivity $\epsilon_r = 10$, $\tan\delta = 0.0035$ and $b = 0.63$ mm), being the perforated rectangle of dimensions $D/2 \times t$. The lateral vias of the SIW are characterized by their diameter d_s and separation s_v, which have been chosen appropriately to avoid radiation losses in the lateral walls of the guide, being in all analyzed cases of $d_s = 0.8$ mm and $s_v = 1.2$ mm. We choose the width of the waveguide $a_{siw} = 23$ mm to fix the cutoff frequency of the initial SIW at about 2 GHz. To characterize the behavior of this periodic structure in a given frequency range, the dispersion diagram of the unit cell must be calculated [1], [20].This has been done by using the commercial software tool Ansys HFSS (see [12], [21]). For this case, a study has been made on how the dispersion diagram is affected by the height t of the rectangular air holes, thus providing different effective permittivity values in the perforated sections. As it is well-known, the modification of the effective permittivity contrast within the periodic cell has a direct effect on the dispersion behaviour of the periodic waveguide [22], in terms of the cutoff frequency on the one hand, and in terms of the band-gaps width and position on the other hand. Fig. 2 shows the dispersion diagram of a periodically perforated SIW with $a_{siw} = D = 23$ mm for different rectangle heights. As it can be appreciated, the cutoff frequency of the waveguide increases with t. This is due to the fact that the mean value of permittivity in the periodic cell diminishes with t. On the other hand, it can also be observed in Fig. 2 that the first band-gap of this waveguide widens significantly with the parameter t. This behavior has already been explained in [20], where it is shown that the band-gap width of the periodic structure

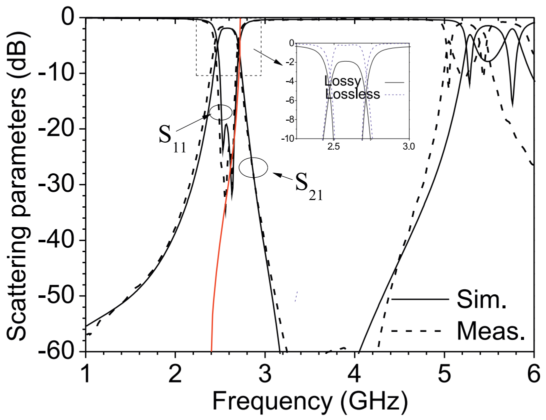

Fig. 9. Electrical response of the SIW filter with CSRRs.

more selective, with a narrower pass-band, but also with a much wider and deeper rejection band, thus making this second topology more suitable for the design of selective filters in S band. However, further investigations must be performed at higher frequency bands, in which a bigger electrical size may not be inconvenient from a resolution point of view in the manufacture of the circuits, and resonant structures may have higher losses.

IV. Conclusion

Periodic SIWs have been applied to the analysis, design and comparison of two band-pass filters in S-band with different types of periodic cell, in order to highlight their advantages and disadvantages. A first filter consisting of periodic rectangular perforations of the dielectric substrate of the SIW has been compared with a second periodic SIW filter with square CSRRs etched on the waveguide surface. The dispersion diagram of the unit cell of each periodic structure has been obtained, showing the dependence of the width and location of the first pass-band and stop-band on the different parameters of the periodic cell, which has allowed the design of a periodic filter based on each proposed topology, highlighting their differences in terms of size and frequency response. Finally, it has been concluded that in the CSRRs-based filter, a much smaller filter with a more selective electrical response is obtained, thus making this second topology more suitable for the design of selective filters in S-band.

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