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Millimeter Wave End-Coupled Resonator Bandpass Filter Based on Ridge Gap Waveguide Technology

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Summary

In ridge gap waveguide concept, by using a metallic ridge between the nails, wave follows the ridge confined to the air gap between the ridge and metallic plate on the top. The main idea of this paper lies on coupling the ridge gap waveguide resonators at the end, called end-coupled resonators. Due to appropriate transient waveguide matching, perfect filter response is achieved. All the steps of design in millimeter wave frequency band are investigated and the exact tuned filter is achieved.

1. Introduction

At millimeter-wave (mm-wave) frequencies, hollow waveguide transmission lines are appropriate solution for low loss transmission lines but machining process of these structures has its own difficulties and expenses due to small dimensions at these frequencies [1]. Furthermore, high dielectric loss and modal coupling problems make microstrip lines and substrate integrated waveguide, inappropriate for integration with MMIC in mm-wave frequencies. Electromagnetic bandgap (EBG) structures are examples of periodic structures prevent propagation of modes at a specific frequency band while we can have hard/soft surfaces work under cutoff frequency conditions (similar to EBG structure, as 1D EBG) whereas these surfaces show propagation cutoff only in one direction [2]. Gap waveguide can be considered based on the concept of hard/soft surfaces that they are ideally like a lumped network of PEC and PMC strips [2], [3]. It is composed of two metal plates in parallel form which one is provided with a texture in the form of as a bed of nails with high impedance condition at surface [4]. In ridge gap waveguide (RGW) concept by using a metallic ridge between nails, waves follow the ridge confined to the air gap between the ridge and metallic plates on the top [5]. The main characteristic of filters based on rectangular or circular shape waveguides are their high quality factor and performance. The main challenge for these filters will be reaching their sizes and weights to be applicable for mobile and airborne platforms. In this paper it is shown that filters in the form of surface technology as microstrips can be implemented in RGW structures. In [6] implementation of end-coupled filter on a printed structure is presented. Here RGW based resonators are coupled with the use of capacitance coupling. The main idea lies on coupling the RGW resonators at the end, called end-coupled resonators, like microstrip resonator filters. Due to noticeable height of RGW resonators, strong coupling can be achieved by this method. Due to appropriate applied transient waveguide matching, perfect filter response is achieved.

2. Filter specifications and end-coupled resonator RGW filter

We will synthesize a coupling matrix for third order filters, Chebyshev type, at Ka-band (center frequency: 35 GHz) [7]. Bandwidth of the filter is 350 MHz, insertion loss is 1 dB and return loss is considered 20 dB. The desired coupling matrix and input/output Q factor for filter of Table 1 is:

$$\boldsymbol{M} = \begin{bmatrix} 0.0000 & 1.0303 & 0.0000 \\ 1.0303 & 0.0000 & 1.0303 \\ 0.0000 & 1.0303 & 0.0000 \end{bmatrix}, \ \boldsymbol{Q}_{ext} = 85 \qquad (1)$$

Frequency response of the above coupling matrix is shown in Figure 1 which meets all the desired design specifications.

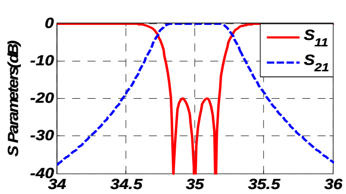


Figure 1. Frequency response of the desired bandpass filter

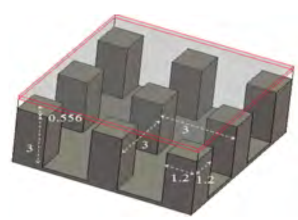
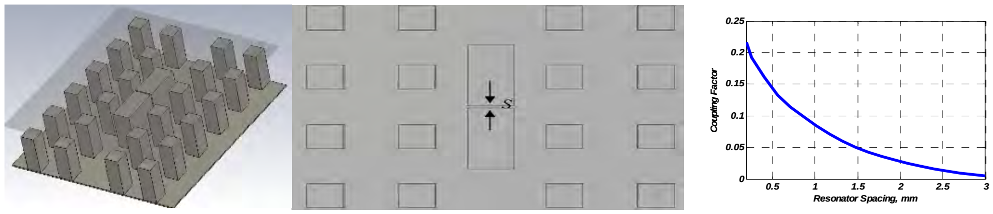


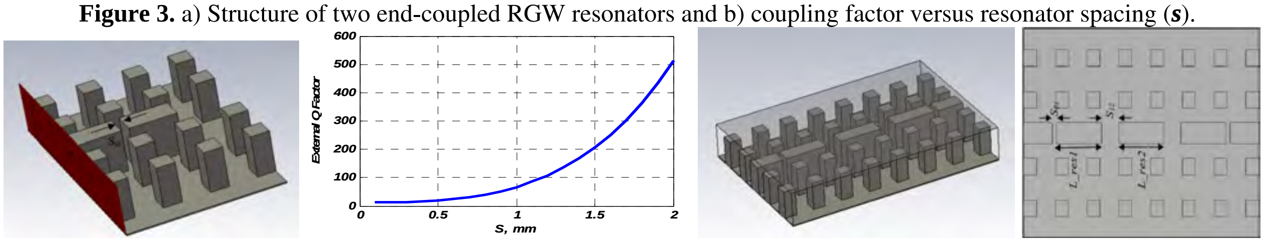
Figure 2. Sizes (mm) for stopband 20 to 40 GHz

First step in the implementation of a device based on the gap waveguide technology is designing the periodic structure. By selecting the values presented in Figure 2 a stopband from 20 to 40 GHz will be achieved. Presented resonators of Figure 2 placed and cascaded in a plate. As it is shown in Figure 3(a), two cascaded RGW resonators are coupled with the use of a spacing. Coupling between resonators is implemented with the use of the strong capacitance effect between the ridges at end of a resonator. Physical structures of two coupled resonators of this filter at the end beside the coupling factor versus resonator spacing (s) are shown in Figure 3(b). It can be seen that coupling coefficient between two resonators can be controlled with changing the resonator spacing distance. In other word coupling coefficient would be decreased by increasing the distance of two resonators (Figure 3(b)). More we make use of another spacing (s_{io}) to have coupling between RGW port and input/output resonators (Figure 4(a)). Figure 4(b) shows that external Q factor would be increased by increasing the distance between resonator and port leads to coupling reduction.



(a) (b)

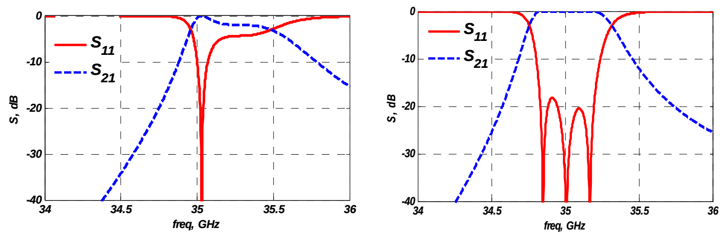
Figure 3. a) Structure of two end-coupled RGW resonators and b) coupling factor versus resonator spacing (***s***).



(a) (b) (c) (d)

Figure 4. RGW resonator structure end-coupled by RGW port and b) external Q factor between RGW port and resonator versus distance between them (s_{io}), c) primitive design of desired end-coupled RGW resonator filter and d) 2D view from top.

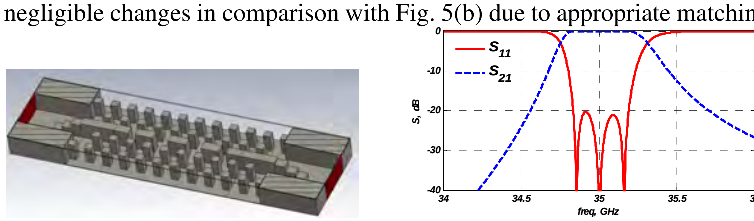
Figure 4(c), (d) shows a primitive design of desired end-coupled RGW resonator filter of order 3 using the above coupling matrix with its primary chosen sizes (L_res1: 2.983, L_res2: 3.086, S01:1.100, S12:2.673). Frequency response of this filter is also presented in Figure 5(a) which is clear that is not well tuned. The main reason is neglecting the input-output port loadings in resonance frequency of input-output resonator and also coupling loading between resonators on resonance frequency of the middle resonators. An optimization technique presented in [8] is used to tune the sizes and optimized sizes can be obtained after five iterations. Figure 5(b) shows the optimized frequency response.



(a) (b)

Figure 5. (a) Frequency response of filter with primitive parameters and (b) Frequency response of optimized filter

Waveguide port WR28 is used as input and output port and added to final tuned filter. Compensation due to adding waveguide ports is implemented and a view of the filter is shown in Fig. 6(a). Fig. 6(b) shows the frequency response of the filter (including waveguide ports), shows negligible changes in comparison with Fig. 5(b) due to appropriate matching in waveguide transition.



(a) (b)

Figure 6. (a) Final designed filter including input/output waveguide ports, (b) Frequency response of the final filter after adding waveguide ports.

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