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EBG Filtering Structure Using Thick Film High Dielectric Constant Resonators

B.Moradi[a*], O.Ymbern[b], J.Alonso[b], J.Garcia[a]

[a]GAEMI, Departament dEnginyeria Electrnica, Universitat Autnoma de Barcelona, 08193 Bellaterra (Barcelona), Spain

[b]Grupo de Sensores y Biosensores, Departamento de Qumica Analtica, Universitat Autnoma de Barcelona, 08193 Bellaterra (Barcelona), Spain

ABSTRACT: This paper reports the design of a stop-pass and band-pass filtering EBG structure operating in the Ku band by using thick film high dielectric constant resonators. The design is based on a micro-strip line that periodically loaded with a new kind of dielectric resonator fabricated with a commercial high dielectric constant epoxy paste which compatible with serigraphy and screen printing technology. The geometry of the resonator has been chosen in such a way that, the filtering structure appears below the first resonant frequency. An equivalent circuit model of the proposed structure is discussed and compared with electromagnetic simulations and measurements.

KEYWORDS: Dielectric Resonator, EBG, Micro-strip Line, Passive microwave circuits

I.INTRODUCTION

Periodically loaded waveguide constitutes a well-known method to synthesize band-pass and stop pass filters in the microwave theory [1, 2]. In this paper, we propose utilization of thick lm dielectric resonators (TFDR) to implement periodically loads on a micro-strip line which is compatible with screen printing, serigraphy and LTCC technologies [3]. Moreover, dielectric resonators have been widely studied and applied to the design of the microwave communication systems from the beginning of the activity in the field [3]. Although, an equivalent circuit model can be used to describe the basic behaviour of the resonator structure, the complexity of the physical behaviour (with multiple resonator modes). And the overwhelming description by equivalent circuit model is necessary of full 3D numerical analysis to optimize the final design. The utilization of high dielectric constant films allows the miniaturization of both active and passive components and reducing the losses [4]. The existence of surface modes in high dielectric constant thick layers has been reported by some of the authors in previous works [5]. TFDR resonant frequencies depend on of both geometrical and dielectric constant field [3]. Although, an equivalent circuit model can be used to describe the basic behavior of the resonator structure, the complexity of the physical behavior (with multiple resonator modes). And the overwhelming description by equivalent circuit model is necessary of full 3D numerical analysis to optimize the final design. The utilization of high dielectric constant films allows the miniaturization of both active and passive components and reducing the losses [4]. The existence of surface modes in high dielectric constant thick layers has been reported by some of the authors in previous works [5]. TFDR resonant frequencies depend on of both geometrical and dielectric constant values, however, the more important parameter for the resonance frequency is the relative permittivity. In the proposed design the first resonant frequency of the TFDR is determined by the cylindrical geometry as well as the value of the dielectric permittivity of the resonator material. Figure 1 shows the simulated resonant mode frequency as a function of the relative permittivity. The geometry of the proposed TFDR consists of a flat cylinder with 0.6 mm height and 1 mm radius. The resonant frequency plotted in Figure1, have been estimated using full 3D EM simulator and it can be seen that the miniaturization possibilities as far as the dielectric constant r increases. Higher values of dielectric constant 40 can be found in the literature for non-commercial ink and pastes, especially for those containing $BaTiO_3$ [6, 7], however, commercial solutions for both ink and paste rarely have dielectric constants above 50. It can be shown that the approximate impedance of a passive resonator can be obtained as a partial expansion of the generic impedance function displayed in Equation 1 (please see [8, 9]).

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$$Z(j\omega) = jX(\omega) = j[A_\infty \omega - \frac{A_0}{\omega} + \sum \frac{2.A_i.\omega}{\omega_i^2 - \omega^2}] \quad \textbf{(1)}$$

According with the Foster synthesis [8], the equivalent circuit model of the passive resonator should be described with the network depicted in Figure 2, where, $C_s = 1/A_0$, $Ls = A_\infty$, $C_{pi} = 1/2.A_i, L_{pi} = 2Ai/\omega_i^2$ In our case, the resonators are used below their first resonant frequency to implement the EBG loads being enough to consider a single series LC branch to fit the filtering pattern exhibited by the experimental data, and therefore to obtain a reasonable description of the dielectric resonator in this frequency range. Notice that the resonant frequency is ruled basically by the dielectric constant value and not for the geometry. In our design the geometrical dimensions are applied to obtain a single resonator mode.

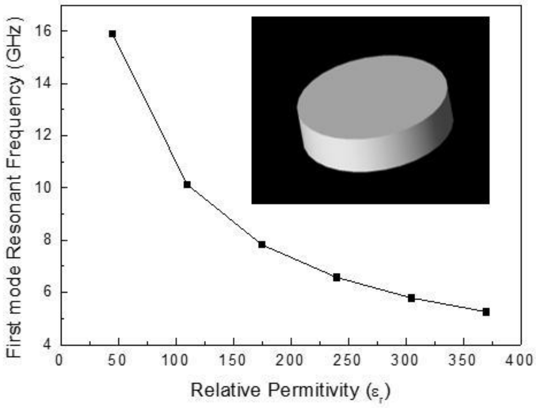

Figure 1: Simulated relation between the resonant frequency mode and the dielectric constant. The cylindrical resonator is 0.6 mm thick with a radius of 1 mm.

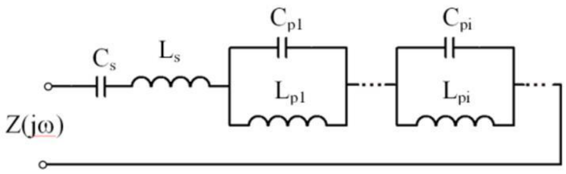

Figure 2: Foster synthesis of equivalent circuit model for any generic passive resonators [8].

1.1. Equivalent Circuit Model

The electronic band gap has been used as an effective way to create microwave filters. In our case the structure is a micro-strip periodically loaded with resonators that can be characterized as series LC branch (showed in Figure 3). The micro-strip host transmission line characteristic impedance Z_0 and propagation constant ε_r be analytically evaluated from the dimensions of the micro-strip line and the physical properties of the substrate which in our case is the 25 mils Rogers RO3010. It can be shown that for a symmetrical passive structure, the dispersion equation is ruled by the equation

$$cos(\beta.d) = cos(\frac{k_0.d}{2}) - \frac{\omega^2.C_R.L_R - 1}{\omega.C_R} sin(\frac{k_0.d}{2}) \quad (2)$$

The proposed design corresponds to a no attenuated propagating wave on the periodic structure, and denes the stop-band of the structure with $cos\beta.d = cos\theta - \frac{b}{2} sin\theta$ definition, where $\theta = kd$, and k is the propagation constant of the unloaded line and b is a shunt susceptance. Where β is the propagation constant of the periodic structure, k_0 is the propagation constant of the micro-strip host line, d is the basic cell length of the equivalent circuit model of the resonators are L_R

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and C_R. The confinement of the right hand of equation 2 between -1 and 1 will determine the transmission bands. In the proposed design it corresponds to a stop-band filtering structure. The proposed design corresponds to a stop-band filtering structure.

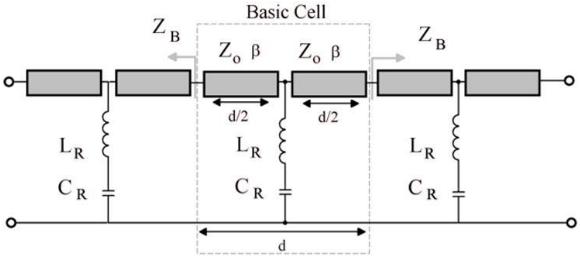

Figure 3: EGB filter structure where the grey boxes represent the micro-strip host transmission line determined by the length of the basic cell d, the propagation constant β and the characteristic impedance Z_0, and the dielectric resonator is modeled by the series L_R - C_R branch.

1.2. Fabrication process

The prototype has been fabricated in a 25 mil thickness Rogers RO3010 with a ε_r = 10.2 and a loss tangent ε_r = 0.0022 at the operating frequencies. Several layers of the creative epoxy paste have been deposited until a thickness of 0.6 mm and radius of 1 mm has been achieved in the resonators. The structures have been cured in a conventional oven at *150^0C* for one hour. A photograph of the fabricated prototype is shown in Figure 4.

1.3. Measurements and discussion

The measurement of the fabricated prototype has been done by using a Vectorial Analyser. Figure 5 illustrates the measured response of the prototype which clearly exhibits the EBG behaviour with successive spurious bands. As can be observed the proposed equivalent circuit model offers an excellent t of the measurements for $L_R = 0.25nH$ and $C_R = 0.07\,pF$.

Figure 4: Picture of the fabricated prototype.

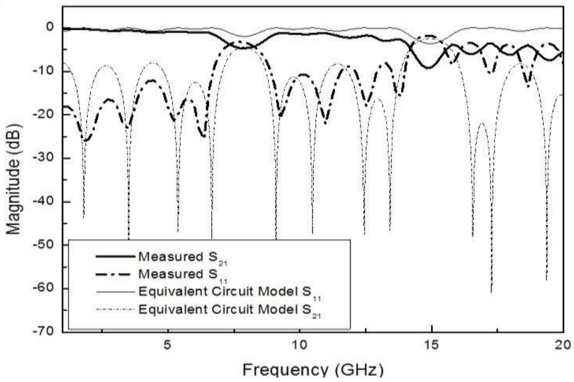

Figure 5: Measured S-parameter for a 3 stage EBG fitted with the equivalent circuit model showed in Figure 3.

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II. IMPROVED DESIGN

To improve high rejection level of S-parameter response, one approach is use of path between input and output ports which the signals are enforced to cancel each other at the output port by proper adjustment of amplitudes and phases. In this case, by modifying the configuration of the prototype by surrounding DRs with micro-strip ring resonator, band-pass could be improved which this part is developed by utilization of micro-strip ring resonator and embedded DRs as resonators in planar devices. The idea of using three DRs is to generate few additional frequencies which can be merged together to produce a wideband device, increase the transmitting power and reduce the insertion loss in the pass-band design. The optimum coupling effect in the filter was obtained from the matching position of the resonators on the micro-strip line. Since cylindrical shape of dielectric resonators have a flexible radius (r), height (h) and dielectric constant due to various sizes can be obtained from the market. The applications of these resonators have been widely used in filters and oscillators. Such shape offers a wide degree of freedom in microwave designs since the ratio of r/h could determine the Q-factor for a given dielectric constant. Thus a height of the slender cylindrical DR can be made to resonate at the same frequency as a wide and thin DR. However, the Q-factors for these resonators would be different. This characteristic offers a flexible degree for choosing the most suitable ratio to be the best frequency and bandwidth. The high Q-factor and compact size make it an ideal couple especially in micro-strip technology

2.1. Proposed Filter

The proposed embedded dielectric resonators (EDR) constitute a new approach to the miniaturized resonators suitable for meta material design without the Q degradation inherent to the coupling coefficient based sub-wavelength particles. The geometry of the proposed structure consists of a three cells EBG. Each cell formed by a cylindrical DR with 2 mm diameter and 1.27 mm height, and 1.3 mm width micro-strip ring resonator with an inner radius of 1.3 mm. The basic structure of the EDR consists in the inclusion of cavities in the PCB design that could be filled with high dielectric constant pastes to generate EDR after the curing process as shown in Figure 6. There are two main advantage of this technique to generate EDRs: the possibility to control the geometry of the resonator and the possibility to combine with standard structures in planar technologies such as micro-strip or coplanar-waveguide. Epoxy dielectric materials with relative permittivity $\varepsilon_r = 45$ is used as DRs.

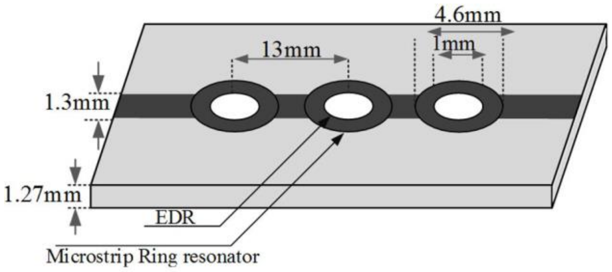

Figure 6: Configuration and 3D model of embedded dielectric resonator.

The DRs fed energy by a 50 micro-strip line of width =1.3 mm and length=50 mm by putting on the top of substrate. The substrate is Roger3010 with dielectric constant of $\varepsilon_r = 10.2$ and loss tangent 0.0022. Each of DRs is resonate for a same mode but with different frequency such that the combination response is an additional result from the single response which able to increase the overall bandwidth.

2.2. Equivalent circuit model

The equivalent circuit model of EDR pass band can be reproduced as an infinite of parallel LC tanks. An equivalent circuit model for proposed filter is used to describe the basic behaviour of the resonator structure as depicted in Figure 7. The micro-strip host transmission line characteristic impedance Z_0 and propagation constant can be analytically evaluated from the dimensions of the micro-strip line and the physical properties of the substrate. It can be shown that for a symmetrical passive structure, the dispersion equation is solved by the equation

$$cos(\beta.d) = cos(k_0.d) - \frac{1-\omega^2.C_R.L_R}{2\omega.L_R} sin(k_0.d) \qquad \textbf{(3)}$$

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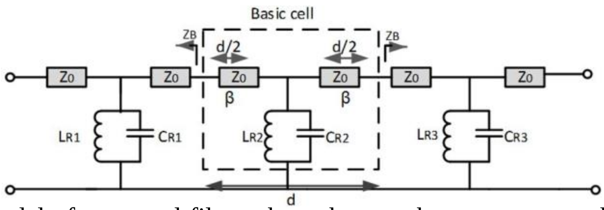

Figure 7: Equivalent circuit model of proposed filter where the grey boxes represent the micro-strip host transmission line determined by the length of the basic cell d, the propagation constant β and the characteristic impedance Z_0, and the dielectric resonator is modelled by the parallel L_R- C_R branch.

2.3. Measurement and discussion

For implementation of proposed filter the 50 mil Roger3010 substrate used as a host which is characterized by a loss tangent δ = 0.0022 and $\varepsilon_r = 10.2$ at the operating frequencies. By drilling an array of circle via-slot patterns in a substrate, waveguide dielectric channel can be created. Layers of the epoxy have been embedded until a thickness of the substrate has been achieved in the resonators. The structures have been cured in a conventional oven at $150^{\text{Å}\circ}C$ for one hour. The fabricated proposed filter is shown in Figure 8, while Figure 8(a) corresponds to a filter with three coupled single ring and in Figure 8(b) with three EDR coupled particles. As can be observed in Figure 9, there is an excellent agreement between simulation, equivalent circuit model and measurement. In the measurement, the lower and higher cut-o frequencies of the EDR filter are equal to 2.75 GHz and 4.6 GHz. This indicates that the relevant fractional bandwidth achieves about 50.5%at the central frequency 3.6 GHz

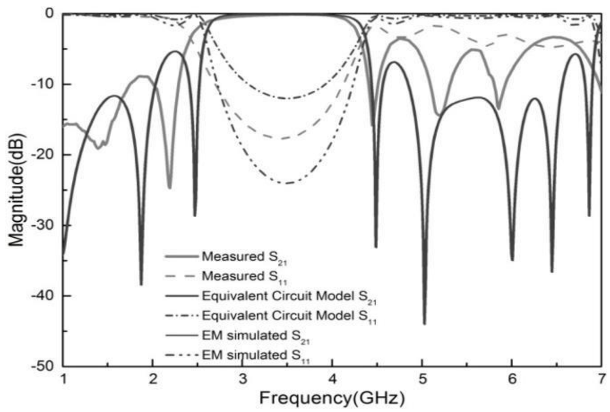

Figure 9: Measured S-parameter for a band pass EBG fitted with the equivalent circuit model showed in Figure 7.

III. FURTHER MINIATURIZATION

To further miniaturize the filter, its e activeness as the value of ε_r increase from 45 to 100, frequency proportional to change of ε_r , shift down from 3.6 GHz to 3.2 GHz respectively, which causes 12% miniaturization filter. S-parameters of EDR in comparison between different dielectric constant are depicted in Figure 10. As can be observed in Figure 10, resonant frequency decreases with ε_r of EDR. The e active permittivity is defined as the square of the ratio of the velocity in free space for any propagating wave; the velocity is given by the appropriate frequency wavelength product. Which in the micro-strip line, the velocity is $v_p = f\lambda_g$ and then

$$\varepsilon_{eff} = (\frac{c}{\lambda_g f_0})^2 \qquad (4)$$

Since the effective permittivity is frequency dependent, increasing as the frequency increases. In EDR, the presence of high r material has the effect to increase the value of the ε_{eff} [10]. The increment of the ε_{eff} can be interpreted as a miniaturization, since it produces a shift toward of resonant to lower frequency. It is notable that further size reduction can be obtained once a substrate with higher permittivity is used.

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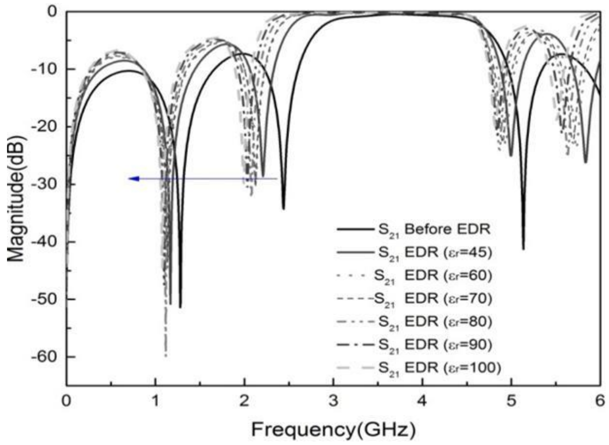

Figure 10: Simulated S_{21} response of the embedded dielectric constant to miniaturize band-pass filter with various dielectric constant from r = 45 to r = 100 and shifting frequency from 3.6 GHz to 3.2 GHz which is 400 MHz frequency shifting down.

CONCLUSIONS

This paper shows the ability of the thick film high dielectric constant resonators to be used as passive elements for the design passive filters in the range of Ku band. The resonator physical complex behaviour leads to the utilization of full 3D electromagnetic software to the design of devices based on these resonators. The proposed structure points out the possibility of using EDR for the creation of EBGs. Further work is under development to improve the utilization of EDR as resonators in planar devices.

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