ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

EBG Filtering Structure using Thick film High Dielectric Constant Resonators

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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 microstrip linethat periodically loaded with a new kind of dielectric resonator fabricated with a commercial high dielectricconstant epoxy paste which compatible with serigraphy and screen printing technology. The geometry of theresonator has been chosen in such a way that, the filtering structure appear below the first resonant frequency.An equivalent circuit model of the proposed structure is discussed and compared with electromagneticsimulations and measurements.

KEYWORDS: Dielectric Resonator, EBG, Microstrip Line, Passive microwave circuits.

I.INTRODUCTION

Periodically loaded waveguide constitutes a well-known method to synthesize band pass and low-pass filters in the microwave theory [1, 2]. In this paper, we propose thick film dielectric resonators (TFDR) to implement loads on a microstrip line, 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) overwhelms the description by any equivalent circuital model, being necessary a full 3D numerical analysis to optimize the final design.

The first resonant frequency of the TFDR used in the proposed design is determined by the cylindrical geometry as well as the value of the dielectric permittivity of the resonator material. CREATIVE 122-06 pad-printable high dielectric constant epoxy paste, characterized by a value of ε_r=45 has been used to point out the possibility of using commercial dielectric pastes.

The utilization of high dielectric constant films allows the miniaturization of both active and passive components 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. Fig. 1 shows the simulated first mode resonant 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 Fig. 1, have been estimated using the simulator. The dielectric paste used in the proposed structure ε_r=45 is in the extreme of the Fig. 1 graph highlighting the miniaturization possibilities as far as the dielectric constant increases. Higher values of dielectric constant 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 (1) [8, 9].

$$Z(j\omega) = jX(\omega) = j\left[A_\infty \omega + \frac{A_0}{\omega} + \sum_{i=1}^{m} \frac{2A_i\omega}{{\omega_i}^2+\omega^2}\right] \quad (1)$$

According with the Foster synthesis [8], the equivalent circuit model of the passive resonator should be described with the network depicted in Fig. 2, where $C_S=1/A_0$, $Ls=A_\infty$, $C_{pi}=1/2A_i$ and $L_{pi}=2A_i/\omega^2_{i.}$

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 as it will be showed in the following sections.

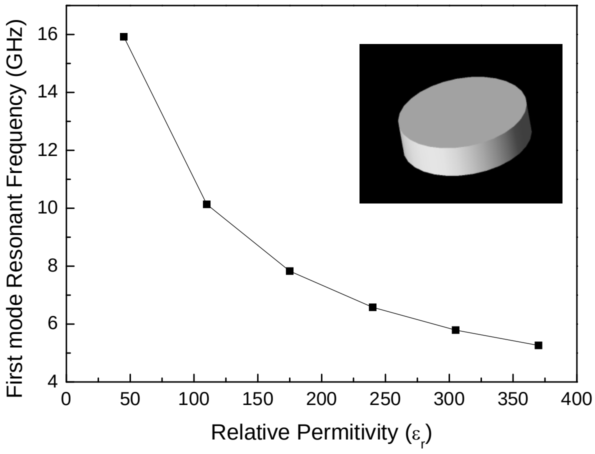


Fig. 1Relation between the first resonant mode frequency and the dielectric constant. The cylindrical resonator is 0.6 mm thick with a radiusof1 mm.

The utilization of higher dielectric constant inks will result in the reduction of the operating frequency as well as a relaxation of the minimum thickness needed to hold resonances and therefore a miniaturization of the resonator. In the case of ε_r=45 a minimum value of 0.6 mm has been fixed according to 3D EM simulation results.

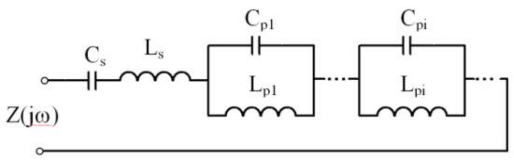


Fig. 2Foster synthesis of equivalent circuit model for any generic passive resonators [8].

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.

II.PROPOSED FILTER STRUCTURE

The electronic band gap has been used as an effective way to create microwave filters. In our case the structure is a microstrip periodically loaded with resonators that can be characterized as series LC branch (showed in Fig. 3).

The microstrip host transmission line characteristic impedance Z_0 and propagation constant β can be analytically evaluated from the dimensions of the microstrip 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 (2) [1]

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

Where β is the propagation constant of the periodic structure, k_0 is the propagation constant of the microstrip host line, d is the basic cell length of the equivalent circuit model of the resonators are L_R and C_R. The confinement of the right hand of (2) between -1 and 1 will determine the transmission bands. In the presented case it corresponds to a low-band filtering structure with successive spurious bands.

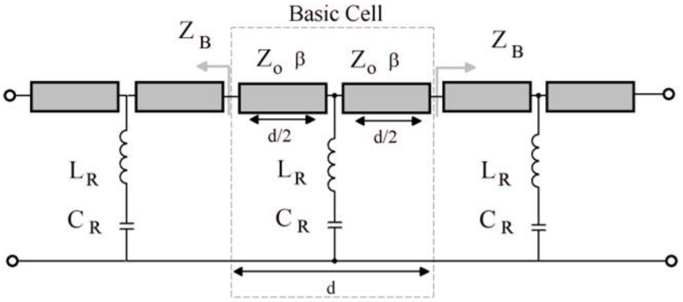


Fig. 3EGB filter structure where the grey boxes represent the microstrip host transmission line determined by the length of the basic cell d, the propagation constant βand the characteristic impedance Z_0, and the dielectric resonator is modelled by the series L_R-C_R branch.

III.FABRICATION PROCESS AND MEASURED RESULT

The used substrate for the host line is a 25 mil thickness Rogers RO3010 with a ε_r=10.2 and a loss tangent δ=0.0022 at the operating frequencies.Several layers of the Creative 122-06 dielectric have been deposited by means of in home fabricated masks until a thickness of 0.6 mm have been achieved in the resonators. The structures have been cured in a conventional oven at 150ºC for one hour. Fig. 4 shows the fabricated device.

Fig. 4 Picture of the fabricated prototype.

The measurements of the fabricated prototype have been done by using a Vectorial analyser as can be observed in figure 5 the proposed equivalent circuit model offers an excellent fit of the measurements for L_R=0.25 nH and C_R= 0.07 pF. Fig. 5 illustrates the measured response of the prototype which clearly exhibits the EBG behaviour.

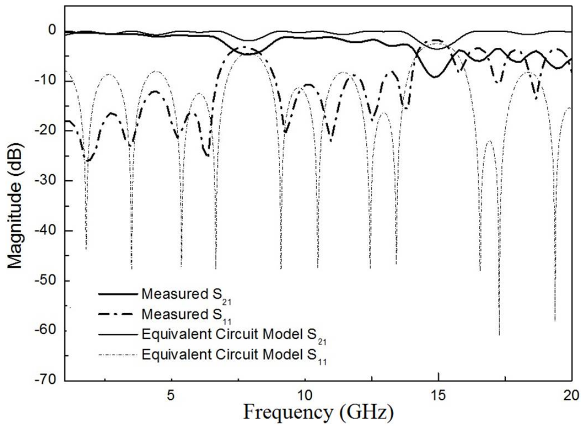


Fig. 5 Measured S-parameter for a 3 stage EBG fitted with the equivalent circuit model showed in Fig. 3.

IV. IMPROVEMENT DESIGN

To improve high rejection level one approach is use of path between input and output ports and 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 microstrip ring resonator, band pass could be improved which next part is development by utilization of microstrip ring resonator and embedded DRs as resonators in planar devices.
The idea of using the 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 microstrip line. Since cylindrical shape of dielectric resonators have a flexible radius, 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 two resonators will 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 microstrip technology.

V. PROPOSED IMPROVED FILTER STRUCTURE

The proposed embedded dielectric resonators(EDR) constitute a new approach to the miniaturized resonators suitable for metamaterial designwithout the Q degradation inherent to the couplingcoefficient based sub-wavelength particles. The geometry of the proposed structure consists of a threecells EBG. Each cell formed by a cylindrical DRwith 2 mm diameter and 1.27 mm height, and 1.3mm width microstrip ring resonator with an inner radius of 1.3 mm. The basic structure of theEDR consists in the inclusion of cavities in thePCB design that could be filled with high dielectric constant pastes to generate EDR after the curing process as shown in Fig. 6. There are twomain advantage of this technique to generate EDRs:the possibility to control the geometry of the resonator and the possibility to combine with standardstructures in planar technologies such as microstripor coplanar-waveguide. Epoxy dielectric materialswith relative permittivity $\varepsilon_r = 45$ is used as DRs.The DRs fed energy by a 50 microstrip line of width=1.3 mm and length=50 mm by putting on thetop of substrate. The substrate is Roger3010 withdielectric constant of $\varepsilon_r = 10.2$ and loss tangent0.0022. Each of DRs is resonate for a same modebut with different frequency such that the combination response is an additional result from the singleresponse which able to increase the overall band-width.

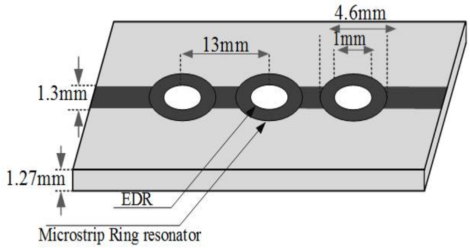


Fig 6: Configuration and 3D model of embedded dielectric resonator.

A. EQUIVALENT CIRCUIT MODEL

The equivalent circuit model of EDR pass bandcan be reproduced as an infinite of parallel LCtanks. An equivalent circuit model for proposedfilter is used to describe the basic behaviour of the resonator structure as depicted in Fig. 7.

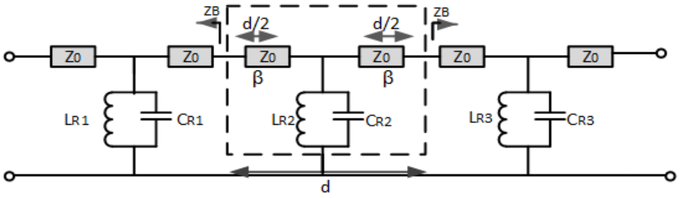


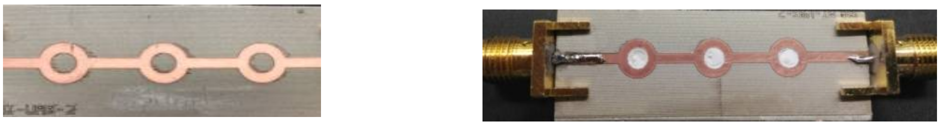
Fig. 7Equivalent circuit model of proposed filter where the grey boxes represent the microstrip host transmission line determined by the length of the basic cell d, the propagation constant β and the characteristic impedance Z_0, and the dielectric resonator is modelled by the parallel L_R-C_R branch.

The microstrip host transmission line characteristic impedance Z_0 and propagation constant β can beanalytically evaluated from the dimensions of themicrostrip line and the physical properties of thesubstrate. It can be shown that for a symmetricalpassive structure, the dispersion equation is solvedby the equation

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

B. MEASUREMENT AND DISCUSSION

For implementation of proposed filter the 50 milRoger3010 substrate used as a host which is characterized by a loss tangent $\delta = 0.0022$ and $\varepsilon_r = 10.2$at the operating frequencies. By drilling an array ofcircle via-slot patterns in a substrate, waveguide dielectric channel can be created. Layers of the epoxyhave been embedded until a thickness of the substrate has been achieved in the resonators. Thestructures have been cured in a conventional ovenat 150°C for one hour. The fabricated proposed filter is shown in Fig. 8, while Fig. 8(a)correspondsto a filter with three coupled single ring and in Fig.8(b) with three EDR coupled particles.



(a) (b)

Fig. 8 Picture of the fabricated prototypes (a) Before embedded with DR b) After embedded with DR.

As canbe observed in Fig. 9, there is an excellent agreement between simulation, equivalent circuit modeland measurement. In the measurement, the lowerand higher cut-off frequencies of the EDR filter areequal to 2.75 GHz and 4.6 GHz. This indicates thatthe relevant fractional bandwidth achieves about50.5%at the central frequency 3.6 GHz.

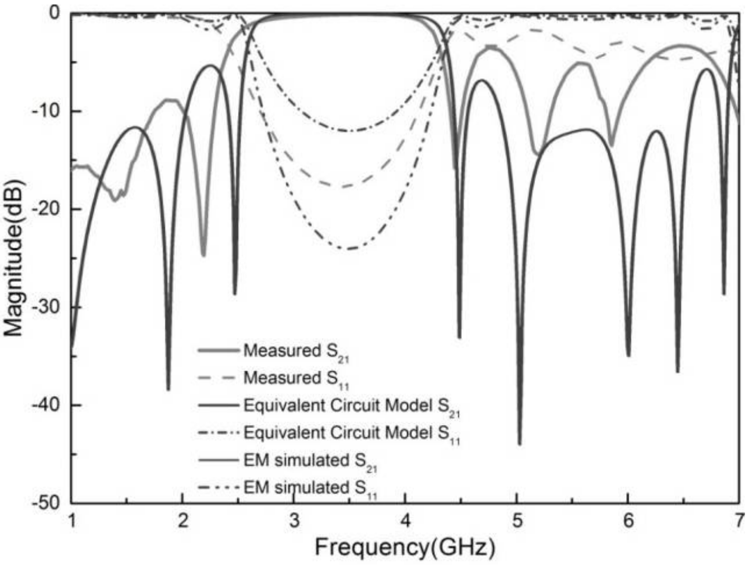


Fig. 9 Measured S-parameter for a band pass EBG fitted with the equivalent circuit model showed in Fig 7.

VI. FURTHER MINIATURIZATION

To further miniaturize the filter, its effectivenessas the value of ε_r increase from 45 to 100, frequency proportional to change of ε_r, shift downfrom 3.6 GHz to 3.2 GHz respectively, which causes12% miniaturization filter. S-parameters of EDRin comparison between different dielectric constantare depicted in Fig. 10. As can be observed inFig. 10, resonant frequency decreases with ε_r ofEDR. The effective permittivity is defined as the square of the ratio of the velocity in free space forany propagating wave; the velocity is given by theappropriate frequency wavelength product. Whichin the microstrip line, the velocity is $v_p = f\lambda_g$ andthen

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

Since the effective permittivity is frequency dependent, increasing as the frequency increases. InEDR, the presence of high r material has the effectto increase the value of the ε_{eff} [10]. The increment230 of the ε_{eff}can be interpreted as a miniaturization,since it produces a shift toward of resonant to lowerfrequency. It is notable that further size reduction can be obtained once a substrate with higher permittivity is used.

VII.CONCLUSIONS

This paper shows the ability of the thick film highdielectric constant resonators to be used as passiveelements for the design passive filters in the rangeof Ku band. The resonator physical complex behaviour leads to the utilization of full 3D electromagnetic software to the design of devices basedon these resonators. The proposed structure pointsout the possibility of using EDR for the creation ofEBGs. Further work is under development to improve the utilization of EDR as resonators in planardevices.

Acknowledgments: This work has been supported by Ministerio deCiencia y Educacin of the Spanish government under the project TEC2010-16060.

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