Coupled Halfwave Microstrip Resonators with Dumbbell Type Defected Ground Structure

Marin Nedelchev, Alexander Kolev[1]

Abstract – **The paper presents design, and simulation of coupled halfwave microstrip resonators with dumbbell type defected ground structures. For the design purposes, the coupling coefficient of the coupled resonators with different sizes of the dumbbell structure is investigated. Each topology is simulated in full-wave electromagnetic simulator and the coupling coefficient is extracted. Design graphs of the coupling coefficients are presented.**

Keywords – **microstrip coupled, resonator, coupling coefficient, defected ground, dumbbell**

I. Introduction

Microstrip filters are key components in the communication systems. They have continuous development in theory and realizations. Edge coupled halfwave microstrip filters are widely used in the practice because of their straighforward design process, easy manufacturing and adjustment, light weight and acceptable size on the printed circuit board. Therefore the improvement of the edge coupled filter characteristics and design process is worth.

One of the problems facing the wideband and ultrawideband filters is the realization of very small gaps between the coupled resonators and the fabrication tolerances connected to their manufacturing. The filter response is also affected by the precision of the manufacturing process of the small gaps. Utilizing different shaped slots in the ground plane of the microstrip line- defected ground structures (DGS) [1-5], it is possible to enhance the coupling coefficient and particularly the electrical coupling. There are proposed different types of DGS topologies in the literature not only for the analysis of the effect of the defects, but also for the implementation of the defects in various structures in microwave filters and devices. DGS is realized by introducing a shape defected on a ground plane so it will disturb the shielded current distribution depending on the shape and dimension of the defect. The disturbance at the shielded current distribution will influence the input impedance and the current flow of the design. The positions and lengths of the dumbbell sections control the response and insertion loss attenuation of the coupled lines. DGS increases the effective values of dielectric constant of substrates (ε_{reff}), thus, decreases the wavelength and the overall length of the design [6].

[1]Marin Veselinov Nedelchev and Alexander Kolev –are with Dept. of Radiocommunication and Videotechnologies in Faculty of Telecommunication in TU –Sofia, N8, Kliment Ohridski bul., 1700 Sofia, Bulgaria. E-mail: mnedelchev@tu-sofia.bg

Fig.1 shows the different defected ground elements' shapes proposed in [1] and the most used DGS element is the dumbbell shaped.

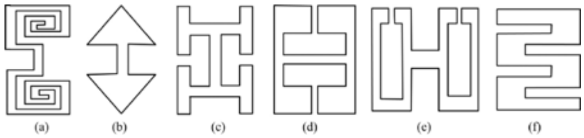

Fig.1 Types of DGS elements-(a) spiral head, (b) arrowhead-shot, (c) "H"-shape slot, (d) a square open-loop with a slot in middle section, (e) open-loop dumbbell and (f) interdigital DGS

Fig. 2 shows the edge coupled halfwave resonators with the dumbbell DGS in the ground plane.

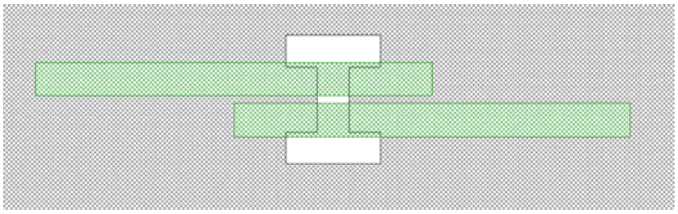

Fig.2 Parallel coupled halfwave resonators with dumbbell DGS

This paper researches the coupling coefficient between two edge coupled halfwave resonators with dumbbell DGS with respect to the variation of its dimensions. As the dumbbell DGS has a lot of degrees of freedom, the coupling coefficients for different dimensions of the dumbbell are computed using a full-wave electromagnetic simulator. The results of the research may be used in microstrip wideband filter design.

II. Dumbbell Defected Ground Structure

All the simulations, design procedures in the paper are performed for dielectric substrate FR-4 with height 1.5mm, relative dielectric constant $\varepsilon_r = 4.4$ and loss tangent $tg\,\delta = 0.02$.

The form of the dumbbell type defected ground structure and its dimensions is shown on Fig. 3. It consists of an main slot connected on both ends to rectangular dumbbell heads.

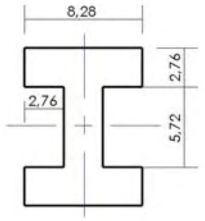

Fig.3. Form and size of the DGS (all sizes in mm)

The edge halfwave coupled resonators have width corresponding to the width of a line with a characteristics impedance of 50Ω. For the dielectric substrate FR-4, it is computed that the width of the line is $w = 2.76\,mm$.

Fig.4 shows two coupled resonators with length l=32.82mm for center frequency $f_0 = 2.4GHz$. The length is determined using a simulation in a full wave EM simulator.

Fig.4 Two coupled resonators with length 32.82mm and width 2.76mm

The responding coupling coefficient for synchronously tuned resonators can be calculated easily by the resonance frequencies of even and odd mode [2], when the coupled resonators are overcoupled:

$$k = \frac{f_e^2 - f_o^2}{f_e^2 + f_o^2} \quad (1)$$

A full wave EM simulator based on the Method of the Moments (MoM) is used to identify the resonance frequencies in the response [7,8].Figure 5 shows the frequency response of the coupled resonators, when there is no DGS and when we place a dumbbell DGS with the form and dimensions shown in Fig.3.

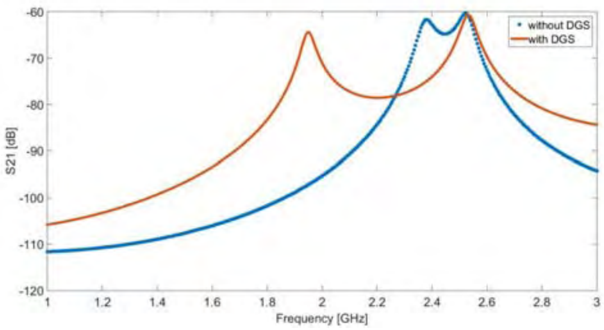

Fig. 5 Frequency response of the coupled resonators with and without dumbbell DGS

It is seen that the slot in the ground plane and the corresponding current disturbance enhances the electric coupling between the resonators. The split resonance frequency of the even mode, when DGS is used, is far away from the split resonance frequency, when no DGS is used. The odd mode resonance frequency is slightly higher than when no DGS is used. Consequently the dumbbell DGS under the coupled resonators enhances the electric part of the coupling coefficient. There is another physical description of this effect. In the microstrip coupled resonators without DGS, in the coupling mechanism many of the electric lines start from the top layer and end on the ground plane passing throught the dielectric substrate. In the presence of the slot a part of these lines are forced to end on the other resonator, enhancing this way the electric part of the coupling. In this way the effective dielectric permittivity for even mode is much higher than the effective dielectric permittivity for odd mode. The DGS topology and size define the coupling coefficient behavior and enhancement.

This fact allows additional degrees of freedom in the synthesis of coupled resonator circuits [9].

III. PARAMETRIC ANALYSIS OF DGS SIZE IMPACT ON COUPLING COEFFICIENT

This section presents the results from the parametric study of the coupling coefficient between coupled halfwave resonators with dumbbell DGS in the ground plane. This parametric study will give the designer comprehensive understanding of the effect of the DGS under the coupled halfwave resonators. The study lead to design curves for coupled halfwave resonators with dumbbell DGS in the ground plane. It will assist the design process of microstrip filters synthesis in the ISM band of 2.4GHz.

The parametric study is performed in full wave EM simulator. Geometrically, the center point of the dumbbell DGS is placed in the center point of the coupled resonators.

Fig.6 shows the four parameter changes in the dumbbell DGS size- head height, head width, slot width and slot height.

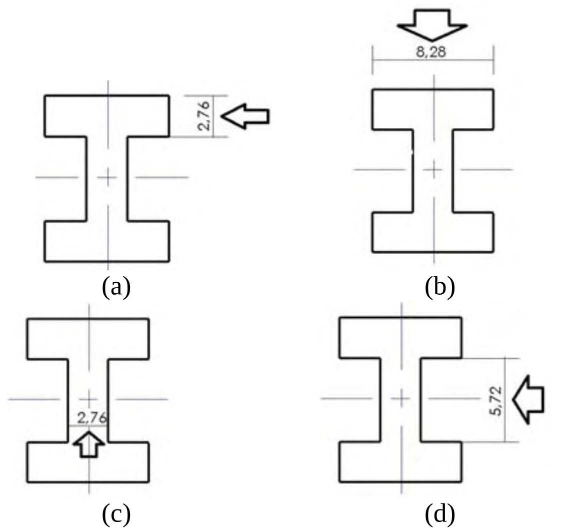

Fig.6 Dumbbell-type DGS size variation.
(a) height of the head, (b) width of the head, (c) width of the slot line (d) length of the slot line

Using full wave EM simulator, the split resonance frequencies in the magnitude response of the coupled resonators are obtained. Using Eq.1, the coupling coefficient is computed for heights of the dumbbell head from 0.2mm to 5mm. All the rest dimensions of the DGS topology remain unchanged. The corresponding family of curves for the coupling coefficient are shown on Fig.7. Generally, the coupling coefficient is monotonically decreasing with the increasing the distance between the resonators. The gap between the coupled resonators is changed discretely from 0.2mm to 3.8mm. As the head of the dumbbell becomes bigger, the coupling coefficient is also increasing. For one and the same gap between the resonators, the value of the coupling coefficient can be at least two times bigger. The height of the dumbbell head has significant impact on the value of the coupling coefficient. It leads to technologically easy tuning of the coupling coefficient by changing the height during the filter adjustment.

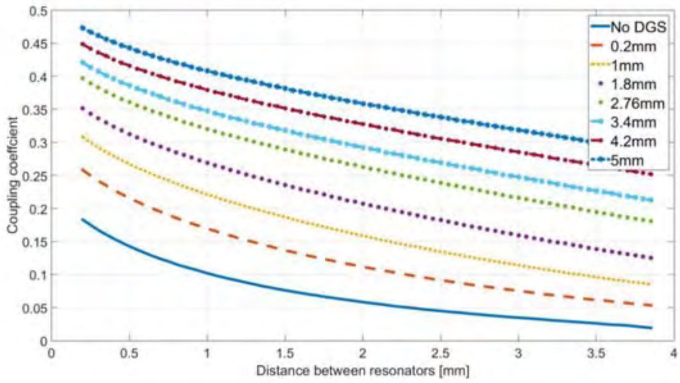

Fig.7 Coupling coefficient for height of the DGS head variation from 0.2mm to 5mm

Fig.8 shows the results from the study of the coupling coefficient, when the width of the DGS head is changed (as shown on Fig.6b). Again, the coupling coefficient is monotonic, but the big increase of the width does not lead to corresponding significant increase of the coupling coefficient. As it is seen from Fig.8, the presence of dumbbell DGS increase at least two times the value of the coupling coefficient.

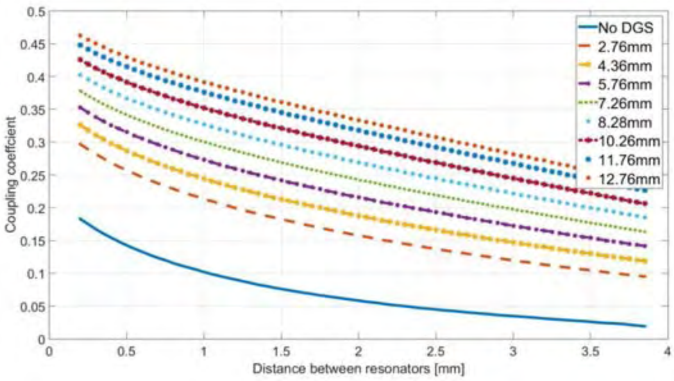

Fig.8 Coupling coefficient for width of the DGS head variation from 2.76mm to 12.76mm

Fig.9 figures out the results for the coupling coefficient when the slot of the dumbbell DGS is changed discretely from 0.2mm to 5.52. The current in the ground plane caused by the slot width is comparably small and the coupling coefficient enhancement is not so well pronounced like the cases when the other parameters are changed. The coupling coefficient increases in 30 to 50% compared to the smallest DGS slot width.

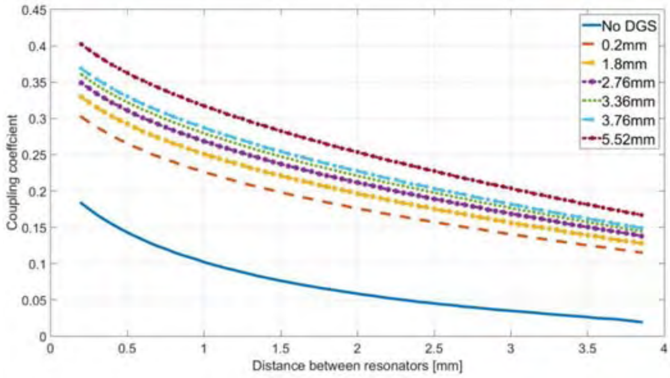

Fig.9 Coupling coefficient for width of the DGS slot variation from 0.2mm to 5.52mm

Fig.10 shows the coupling coefficient dependence on the distance between the resonators and the length of the slot of dumbbell DGS. The values of the coupling coefficient are at least 25% bigger than the values without DGS. The higher is the length, the bigger is the coupling coefficient.

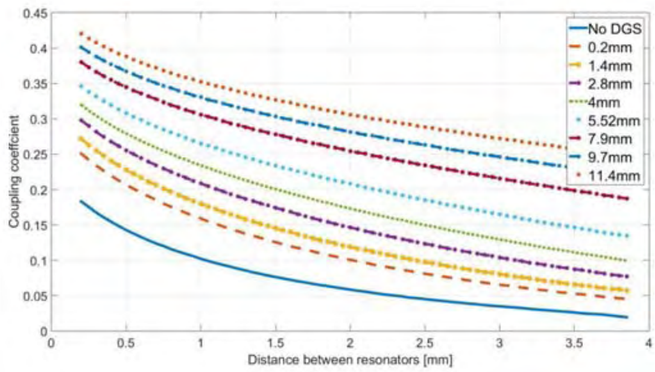

Fig.10 Coupling coefficient for length of the DGS slot variation from 0.2mm to 11.4mm

The parametric study of the coupling coefficient between coupled halfwave resonators confirm the assumption, that introduction of defects of specific topology in the ground plane of the microstrip technology will enhance it. This approach may be used in the wideband and ultrawideband microstrip filter design. From the study it was described the mechanism of the coupling coefficient increasing. The derived design graphs can be used by microstrip filter designers for the ISM band on 2.4GHz.

IV. Conclusion

This paper presents the coupling coefficient between two edge coupled halfwave resonators with dumbbell DGS with respect to the variation of its dimensions. The coupling coefficient between the resonators is derived using the split resonance method. The results from the studies are presented in several design graphs. They can be used in microstrip filter design in the ISM band on 2.4GHz on FR-4 substrate.

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REFERENCES

[1] L.H. Weng, Y.C.Guo, X.W. Shi and X.Q.Chen, “An Overview on Defected Ground Structure”, Progress In Electromagnetics Research B., vol. 7, pp. 173-189, 2008.

[2] J.Hong, M.J Lancaster, "Microstrip Filters for RF/Microwave Applications", John Wiley and Sons Inc, 2001.

[3] G.Breed, “An Introduction to Defected Ground Structures in Microstrip Circuits”, High Frequency Electronics, pp 50-54, 2008.

[4] C.Carg, M.Kaur, “A Review of Defected Ground Structures (DGS) in Microwave Design”, International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol.2 Issue 3, 2004.

[5] S.K. Parui, S.Das, “A New Defected Ground Structure for Different Microstrip Circuit Applications ”, Radioengineering Vol. 16 No 1, 2007.

[6] D.M. Pozar, “Microwave Engineering”, John Wiley and Sons Inc., 2012.

[7] D.G. Swanson Jr, W.J.R Hoefer, “Microwave Circuit Modeling Using Electromagnetic Field Simulation”, Artech House 2003.

[8] D.B. Davidson, “Computational Electromagnetics for EF and Microwave Engineering”, Cambridge University Press, 2005.

[9] Z.Hou, X. Li and C. Hao, “Design of Wideband Filter Using Split-ring Resonator DGS”, Progress in Electromagnetics Research Symposi,China, March 24-28, 2008.