Tri-band Coupler Based on Patch Resonator with Peano Fractal Curve Elements

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Abstract - **In this paper we propose a compact tri-band coupler that consists of a patch resonator with Peano fractal curve elements. The behavior of the proposed structure is analyzed in detail and using its properties a tri-band coupler operating at 0.96/1.57/2 GHz has been designed. The coupler is characterized by good performance in all three bands and very compact size of 0.20x0.23 λ_g^2.**

Keywords - **tri-band coupler, patch resonator, patch coupler, peano curve**

I. Introduction

Rapid development of communication technology has imposed an increasing demand for miniature, low-cost passive devices capable of high performance. In addition, the devices are required to operate at two or more non-harmonically related frequencies which makes their design even more demanding.

Branch line couplers play an important role in every communication device and recently a significant effort has been dedicated to development of multiband couplers. Whilst there have been proposed a number of dual-band couplers [1-10], only several couplers operating at three bands have been published so far [11-16].

The couplers shown in [11-13] use Pi-type networks instead of conventional transmission lines to achieve tri-band operation. However, these couplers exhibit large overall size. Other tri-band couplers were realized with composite right-left handed transmission line [14], artificial transmission lines with lumped elements [15] and non-uniform transmission lines [16] and whilst they are compact, they do not exhibit good performance in all three bands.

The rectangular patch resonator and its specific resonant behavior have been widely utilized in the design of various passive devices such as antennas and filters especially because of their better power-handling capability in comparison to conventional transmission lines. However, patch structures have been rarely used in coupler design and in this work we show a possibility of employment of patch resonator for design of tri-band coupler. By introduction of the slots in the patch structure and by embedding of the elements that have shape of Peano fractal curve, a coupler that operates at three bands can be designed. At the same time, the structure has very small dimensions since it employs fractal curves which have been proven to enable miniaturization of microwave passive circuits [17].

To demonstrate applicability of the proposed structure, a coupler that operates at 0.96/1.57/2 GHz has been designed. It is characterized by very compact size in comparison to other published tri-band couplers, by good isolation and return loss, quadrature phase and 3 dB power split in all three bands.

II. Structure Design

Fig. 1 shows the layout of the proposed tri-band coupler. The structure has been designed on 1.6 mm thick FR-4 substrate with ε_r = 4.2 and *tanδ* = 0.018.The proposed structure is comprised of a rectangular patch with four embedded elements that have the shape of Peano fractal curve. The physical parameters of the Peano elements are shown in Fig. 2.

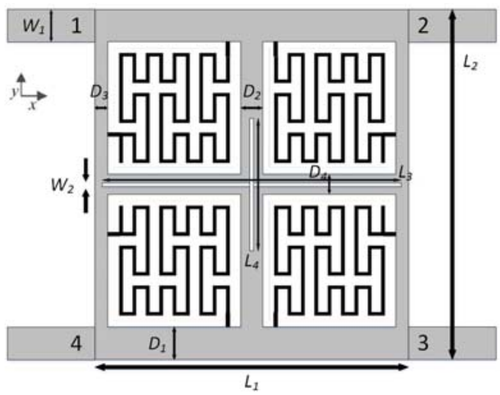

Figure 1: *Proposed tri-band coupler with Peano fractal curve elements*

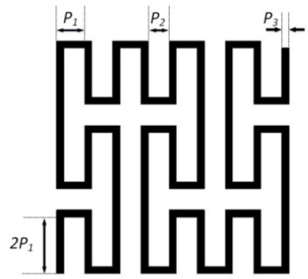

Figure 2: *Peano fractal curve element*

The basic structure of the coupler is a rectangular patch resonator whose fundamental resonant modes are TM_{100}^{z} and TM_{010}^{z}. The electric field distribution for the fundamental and higher-order modes is shown in Fig 3. Fig. 4(a) shows a rectangular patch coupler whose dimensions are L_1 = 36 mm and L_2 = 36 mm, whilst the Fig. 4 reveals its response. It can be seen that this simple structure exhibits operational band at 2.1 GHz which is however not properly matched. This band corresponds to TM_{100}^{z} mode, and although other patch resonant modes occur in the frequency range, there are no other operational bands of the coupler, which is due to poor impedance matching in the structure.

It is also important to note that only those modes that exhibit phase difference equal to 90º between the output ports, Fig. 1, can be used for operational bands of the coupler. Therefore, modes such as TM_{110}^{z} cannot be used for design of the coupler since it does not provide the appropriate field distribution.

It has been shown that introduction of slots in the rectangular patch can decrease the resonant frequencies of the modes due to increased current path [18]. Fig. 4(b) shows a patch coupler with four identical rectangular slots and one cross-like slot. The introduced slots decrease the resonant frequencies of the patch resonator and consequently the operational frequency of the coupler, which is now equal to 1.6 GHz, Fig. 5. Also, there is another operational band at 3.25 GHz which is not properly matched. Similarly to the previous patch structure, this structure exhibits only two operational bands although other patch resonant modes occur in the frequency range, which implies that this structure also suffers from poor impedance matching.

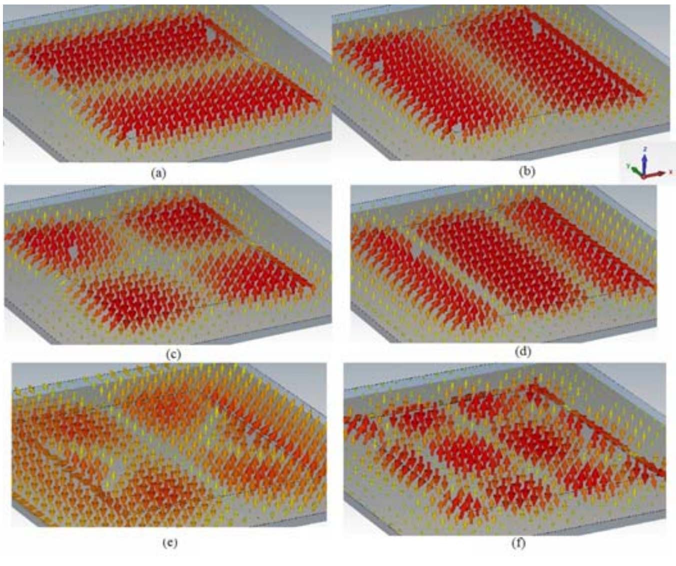

Figure 3: *Electric field distribution for modes (a)* TM_{010}^{z} *(b)* TM_{100}^{z} *(c)* TM_{110}^{z} *(d)* TM_{200}^{z} *(e)* TM_{300}^{z} *(f)* TM_{320}^{z}

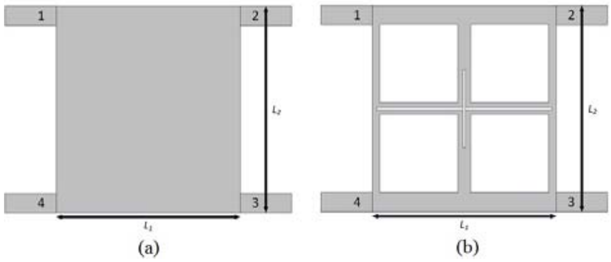

Figure 4: *(a) Rectangular patch coupler (b) rectangular patch coupler with perturbations*

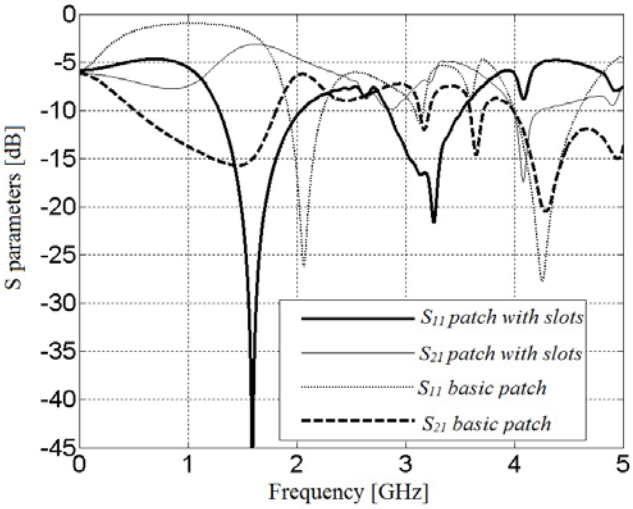

Figure 5: *Comparison between the basic rectangular patch – slotted line, and the patch with slots – full line*

The rectangular slots can be used to host additional elements that can further increase the current path and ultimately decrease the resonant frequencies of the patch modes. To utilize the area of the slot in an optimal manner, we use elements that have the shape of Peano fractal curve of the second order which fill the slots to great extent, and at the same time, provide that the segments of the curves do not significantly interfere with each other. Also, Peano elements allow the control of the operating frequencies since there are several geometrical parameters that can be varied. Furthermore, they allow the control of the impedance matching due to the possibility to connect the ends of the curve to the slots' edges at different points. In that manner, impedance matching in several operational bands can be achieved.

In order to fully understand the behavior of the proposed structure its resonant modes have been analyzed in detail. Fig. 6 shows electrical field distributions of the several resonant modes of the structure. It can be seen that in spite of being rather complex, these modes correspond to those of the conventional patch structure. In other words, the structure represents a patch structure whose modes are slightly disturbed due to introduced slots and elements.

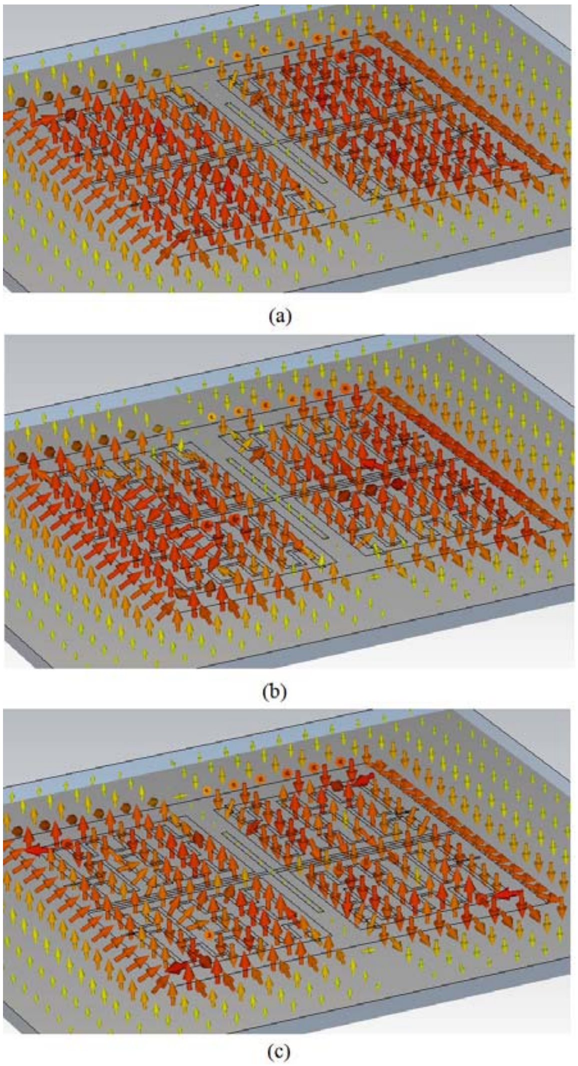

Figure 6: *Electric field distribution in the proposed structure for modes (a) TM_{100}^{z} (b) TM_{300}^{z} (c) TM_{320}^{z}*

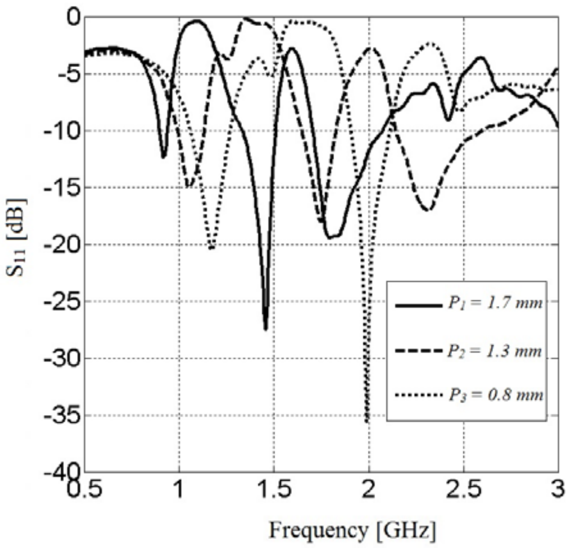

Figure 7: *The effect of Peano fractal curve size on operating frequencies*

The resonant frequencies of the modes can be varied by the change in geometrical parameters of the Peano elements, while preserving overall dimensions of the structure. Fig. 7 shows that increase of the parameter p_1 decreases all resonant frequencies. Nevertheless, not all resonances are influenced to the same extent, i.e. there is a room for independent control of the resonant frequencies. We also note that Peano elements in this configuration allow resonant frequencies variation of up to 30%.

The proposed structure can be used to design tri-band coupler. In order to achieve compact coupler we choose a patch resonator whose dimensions are sufficient to fit rectangular structures, i.e. whose area is slightly larger than the area occupied by the rectangular slots. Also, dimensions of the patch and holes are determined so that, once the Peano elements are introduced, the operational bands are positioned close to the desired frequencies. The operational bands are finely tuned by the geometrical parameters of the Peano elements.

III. TRI-BAND PATCH COUPLER

To demonstrate the applicability of the proposed structure a tri-band coupler has been designed to operate at 0.96/1.57/2 GHz. As it was stated previously, only those modes that exhibit phase difference equal to 90º between the output ports, can be used for operational bands of the coupler. Therefore, to achieve tri-band response, TM_{100}^{z}, TM_{300}^{z}, and TM_{320}^{z} modes are used, as the lowest three resonant modes with appropriate field distribution.

The positions at which Peano elements are connected to the slots' edges strongly influences the impedance matching in the operational bands and thus a special attention has been paid to this aspect of the design. In order to illustrate this effect, two couplers with different configurations of Peano connecting positions, A and B, have been analyzed, Fig. 8. The response of the couplers is shown in Fig. 9. Our investigation has shown that the best results are achieved if the elements are connected as in the position A, Fig. 8(a).

The geometrical parameters of the final structure are as follows: L_1 = 36 mm, L_2 = 39.6 mm, L_3 = 35.5 mm, L_4 = 22 mm, W_1 = 3.5 mm, W_2 = 0.5 mm, D_1 = 3.2 mm, D_2 = 1.4 mm, D_3 = 1.75 mm, D_4 = 1.6 mm, P_1 = 1.6 mm, P_2 = 1.2 mm, P_3 = 0.4 mm.

The simulated results of the designed coupler are shown in Fig 10. It can be seen that the coupler exhibits tri-band operation at the frequencies of 0.96, 1.57, and 2 GHz. The return losses are -13.6, -21, and -40 dB, whilst isolation is -14.6, -17.5 and -26 dB, respectively. S_{21} and S_{31} are -3.74 dB and -3.94 dB in the first band, -3.67 dB and -3.73 dB in the second, and -3.7 dB and -3.6 dB in the third band. The phase difference between ports 2 and 3 in the three bands is shown in Fig. 11. The overall dimensions of the coupler are only $0.20\lambda_g$x$0.23\lambda_g$.

Table I shows the comparison between the characteristics of the proposed coupler and other published tri-band couplers. It can be seen that the coupler proposed in this paper presents the most compact design, which simultaneously exhibits excellent performances in all three bands.

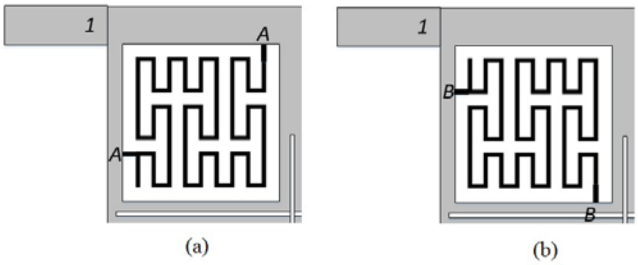

Figure 8: *Two configurations of connecting positions between the Peano curve fractal and the edges of the slot*

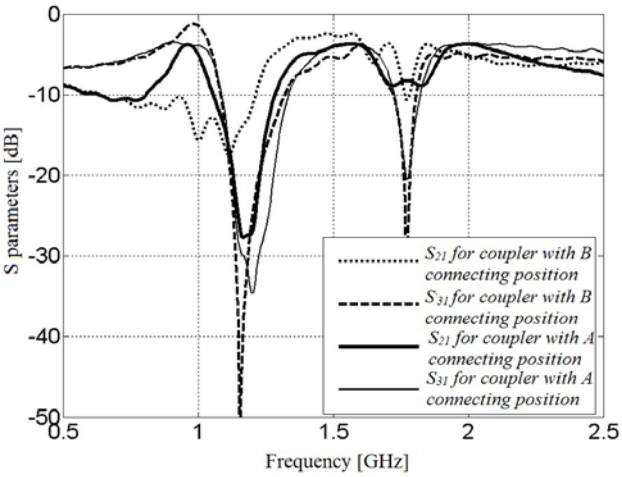

Figure 9: *S parameters of the couplers with connection position A and B*

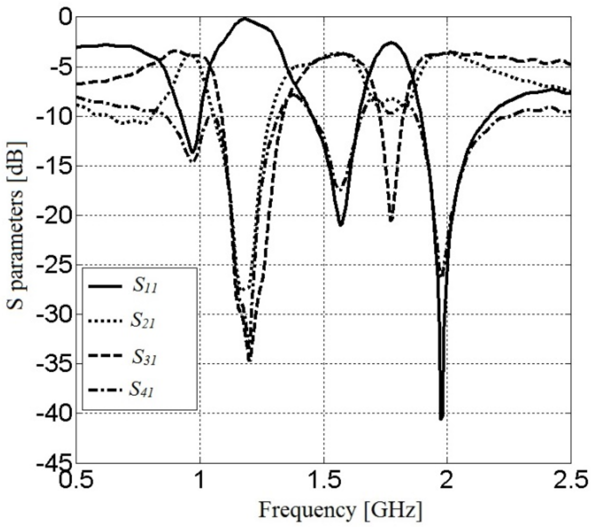

Figure 10: *S-parameters of the proposed tri-band coupler*

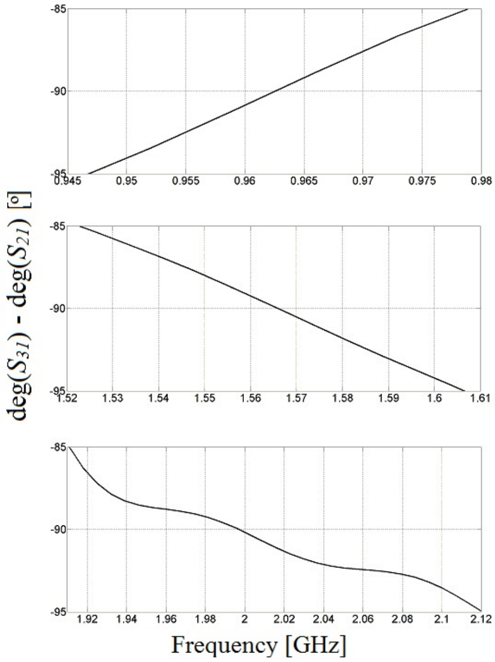

Figure 11: *Phase difference between port 2 and port 3*

Table I *Comparison of the characteristics between the proposed coupler and the previously published couplers*

	This work	[11]	[12]	[13]
$f_1/f_2/f_3$ [GHz]	0.95/1.55/2	1.5/2.4/4.2	0.9/2/2.45	1/2.5/4.5
S_{11} [dB]	13.6/21/40	15.5/17.3/ 15.5	15/15/15	16/16/16
S_{21} [dB]	3.74/3.67/ 3.7	3.85/3.46/ 4.1	3.8/4.2/ 4.2	3.06/3.64 /3.4
S_{31} [dB]	3.94/3.73/ 3.6	3.27/3.39/3.4	3.8/4.2/4.2	3.01/3.42/ 3.9
S_{41}[dB]	14.6/17.5/ 26	17/16.5/14.8	15/15/15	20/20/20
BW_{3° [%]	3.5/5/10.5	6.6/6.6/4.5	4/2/1.6	5/3/2
BW_{1dB} [%]	7.2/12.2/11	7.3/10.4/7.15	4/2/1.6	10/5/3
Dimen. [$\lambda_g x \lambda_g$]	0.20 x 0.23	0.53 x 0.57	0.40 x 0.40	0.44 x 0.45

IV. Conclusion

In this paper, a novel tri-band patch coupler has been proposed. The coupler consists of a rectangular patch in which slots and Peano curve elements have been introduced. It operates at 0.96/1.57/2 GHz and is characterized by good transmission, isolation, and return loss. Besides good performance, the coupler is also very compact, with the overall size of only $0.20\lambda_g x 0.23\lambda_g$.

V. Acknowledgment

This work was supported by the Serbian Ministry of Education, Science and Technological Development through the projects III 43002 “Biosensing Technologies and Global System for Continuous Research and Integrated Ecosystem Management” and III 44003 “Integrated System for Fire Detection and Estimation of Fire Growth Based on Real-Time Parameters Monitoring”.

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