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Design and Fabrication of the Novel Miniaturized Microstrip Coupler 3dB Using Stepped Impedance Resonators for the ISM Applications

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Abstract

In this work, a novel miniaturized compact coupler using the shunt-stubs artificial transimission lines with high and low impedances is presented. Design of the proposed coupler is accomplished by modifying the length and impedance of the branch lines in the conventional structure with the planar resonators in order to achieve branch line coupler with compact size and improvement of the performances. First part of this work is focusing on the theorical study of the proposed resonators where the equations are obtained. Secondly, the proposed coupler is designed on FR4 susbtrate, and simulated by using the EM Solver (ADS from Agilent technologies and CST microwave studio) in order to operate in the ISM band. The obtained results show good agreement with the simulations and the coupler shows a good perfo6rmance in the hole bandwidth. The size of the proposed coupler is reduced around 50% compared to the conventional design. The last part conerns the fabrication and test of the proposed coupler. The measurement and simulation results are in good agreements.

Keywords: *Microtsrip; Miniaturization; Low cost; High and low open stubs; ISM applications.*

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1. Introduction

Recently, the modern wireless communication systems know a rapid development. The passive microwave circuits such as couplers [1,2], power dividers [3,4] play an important role for the development of the wireless communication systems. The couplers are used in transmitting and receiving RF and microwave systems to divide or combine power simultaneously, they are widely used in different microwaves circuits, such as antenna feeding networks, balanced amplifiers, mixers and phase shifters [5-7].

Miniaturization, compactness and high performances of the couplers are important factors to meet the demand of many microwave communication systems. However, at the low frequencies the size of a conventional branch-line coupler is very large. Hence, the size reduction of this device is highly desirable for modern communication systems. Several techniques and methods have been developed in order to miniaturize and improve the peformracne of the conventional coupler [8-13], such as as shunt lumped capacitors with short high impedance transmission lines, two-step stubs, high and low impedance open stubs, stepped impedance stub lines, artificial transmission line, distributed capacitor inside the area of coupler, planner transformer coupling method, and discontinuous microstrip lines [14-20]. The use of shunt-stubs the artificial transmission lines is still the best solutions to design a compact coupler with high performances in terms of size, volume, facilate integration, bandwidth, easy fabrication and low cost.

In this work, the appraoch of the shunt stubs of the open artificial transmission line type is proposed. The open stub is chosen in order to avoid the use of the vias which uses for the case of the short stub. So, this work is organized as follows. Section 2 focuses on theorical study of the proposed resonators. Section 3 presents the design of the proposed coupler by using the Electromagnetic solvers and discussion of the simulation results. In Section 4, the fabrication and measurements of the propsed coupler is presented and discussed. Finally, the conclusion will be presented in Section 5.

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2. Theorical Study of the Proposed Coupler

The branch-line coupler employs quarter-wavelength transformers to realize a simple square-shaped configuration illustrated in Figure 1 it is generally used for distribution to 3dB of energy inserted from input port (port1), with a phase difference of 90° between the way “direct” (port 2) and the way “coupled” (port 3), while the port 4 is isolated port.

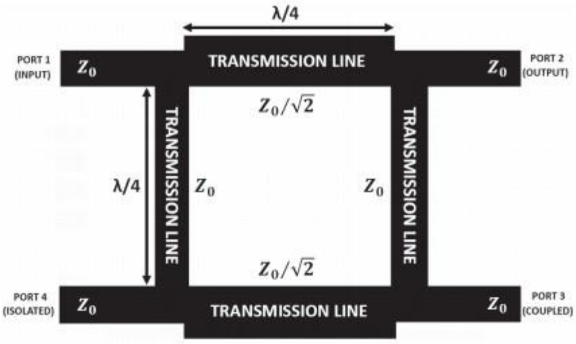
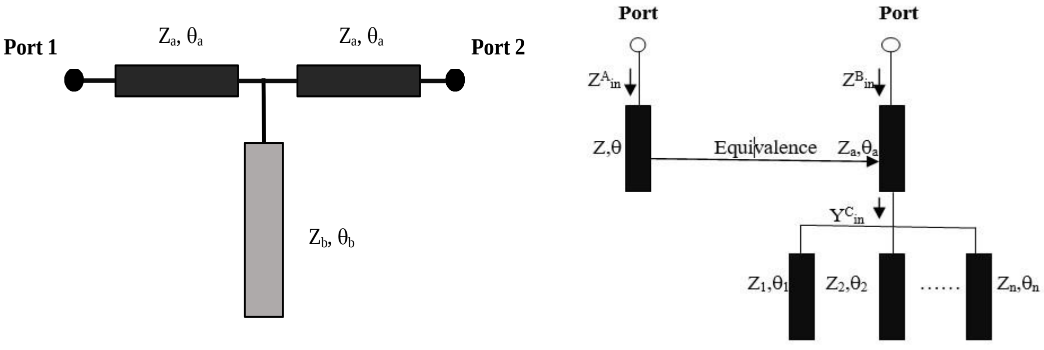


Figure 1. Configuration the conventionnal branch line coupler 3dB.

In order to further miniaturize and improve the structure of the conventional coupler. The novel resonators using Shunt-stubs artificial transmission line is proposed to design a more compact coupler having good performances in terms of the matching, insertion loss, isolation, bandwidth, miniaturization, and low cost. For the quarter wavelength microstrip line with impedance Z0 of the conventional coupler. The resonator combined of the T-model and open stubs model respectively illustrated in Figure 1(a) and Figure 1(b) is proposed to use in place of the conventional transmission line.



(a) (b)

Figure 2. Configuration of the proposed resonator structure combined of, (a) T-model and (b) open stubs model.

According to the equivalence between the ABCD matrix of the quarter wavelength transmission and the T-model [21-23], we get a system of two equations (1) and (2):

$$Z_a = \frac{Z_0}{\tan(\theta_a)} \tag{1}$$

$$Y_b \tan(\theta_b) = \frac{2}{Z_a \tan(2\theta_a)} \tag{2}$$

The equation of the open stubs depicted in Figure 2.(b) is expressed as follow [21-23:

$$\frac{Z_a\tan\theta - Z_0\tan\theta_a}{Z_a^2\tan\theta_a\tan\theta + Z_0 Z_a} = Y_1\tan\theta_1 + Y_2\tan\theta_2 + ... + Y_n\tan\theta_n \tag{3}$$

The obtained equations lead to determine the values of the all electricals dimensions of the T-model and open stubs model. Then, thanks to LinCalc tool of the ADS Agilent, The values obtained of all electricals dimensions are converted to the values of physic dimensions (L1,W1,L2,W2,L3,W3). The obtained values of the dimensions are listed in Table 1.

Table 1. Parameters values of the proposed resonator combined the T-model and open stubs model

Parameter	Value (mm)
L1	9.1
W1	1
L2	3
W2	0.6
L3	5
W3	0.4

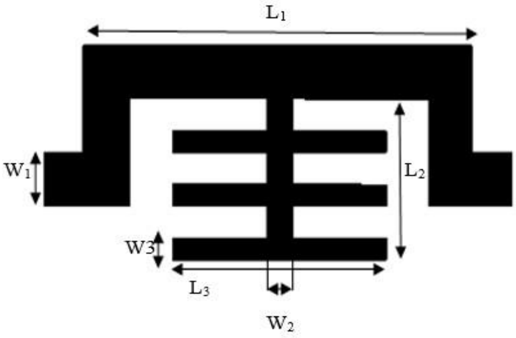
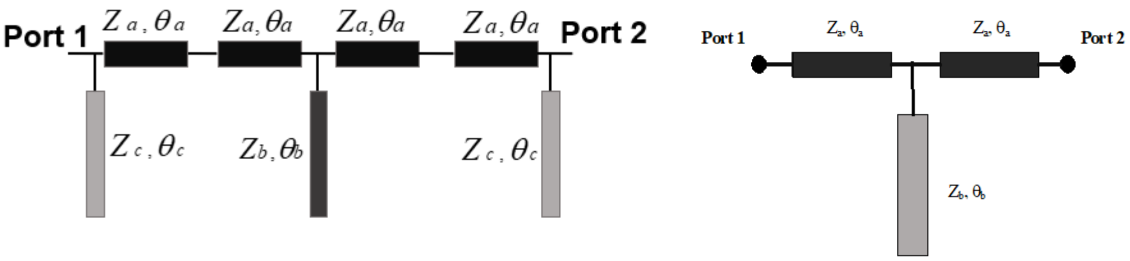


Figure 3. Geometric structure of the proposed resonator combined the T-model and open stubs model.

While the quarter wavelength microstrip line with impedance Z0/√2 is replaced by the resonator combined of the combinational-model and T-model illustrated in Figure 4(a) and Figure 4(b), respectively.



(a) (b)

Figure 4. Configuration of the proposed resonator structure combined of, (a) combinational-model and (b) T-model.

The combinational-model of the Π-model and T-model is expressed by the system of the three equations [21-23]:

$$Z_a = \frac{Z_o(\sqrt{\cos^2 2\theta_a + 4} - \cos 2\theta_a)}{2\sin 2\theta_a} \tag{4}$$

$$Y_b\tan\theta_b = \frac{Z_a\sin 4\theta_a - Z_o}{(Z_a\tan 2\theta_a)^2} \tag{5}$$

$$Y_c \tan\theta_c = \frac{Z_o \cot 2\theta_a - Z_a}{Z_o Z_a} \qquad (6)$$

The physic dimensions of the proposed resonator are calculated by using equations (4,5,6) and LineCalc tool from ADS. The final values of the physic dimensions are shown in Table 2.

Table 1. Parameters values of the proposed resonator combined of the Combinational-model and T-model

Parameter	Value (mm)
L4	12
W4	1.5
L5	5
W5	1
L6	4.1
W6	0.8

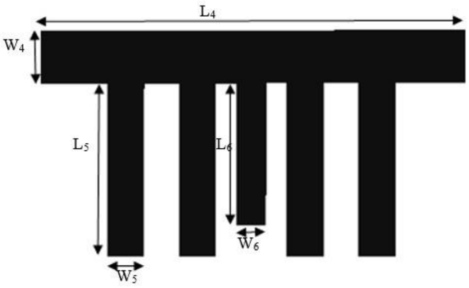
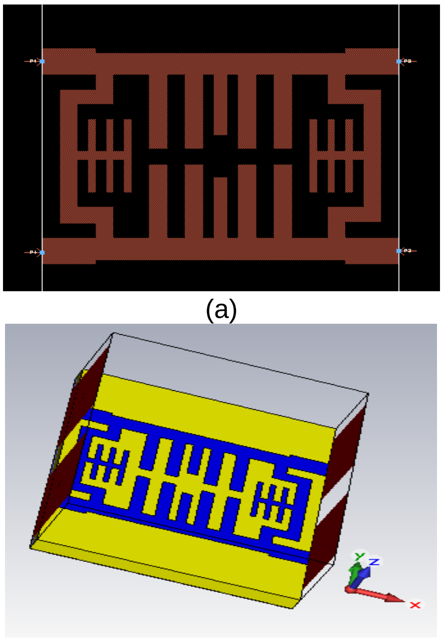


Figure 5. Geometric structure of the proposed resonator combined the T-model and open stubs model.

3. Design and simulation results

The circuit of the proposed coupler is designed at 2.45 GHz on FR4 substrate (ε=4.4, tanδ=0.025) with 1.58 mm thickness. In order to verify the accuracy of the design, the simulation is carried out on both Momentum of ADS and CST Microwave Studio. Figure 6 shows the layout 2D using Momentum ADS and the layout 3D using CST. As we can see, its structure is relatively simple as it can be fabricated on a single layer printed-circuit board, with a simple ground plan. The proposed coupler has an overall size of 20mm×25mm, it occupies 50 % circuit size compared to the conventional structure. The simulation results are compared and depicted from Figure 7 to Figure 9.

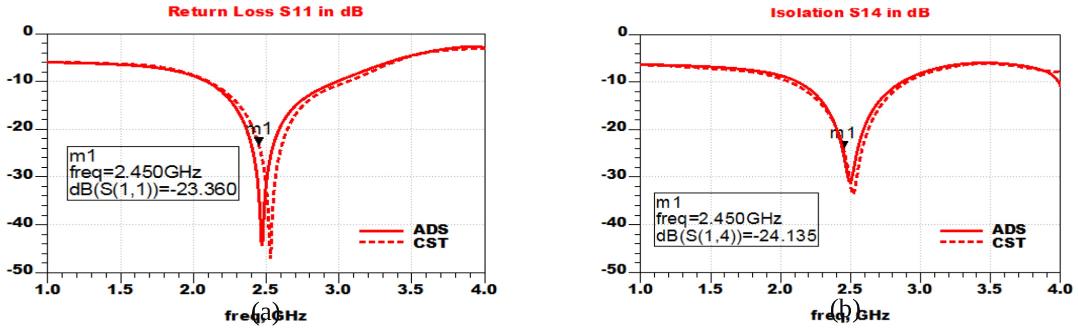


(a)

(b)

Figure 6. The layout of the proposed coupler, (a) Momentum ADS, (b) CST.

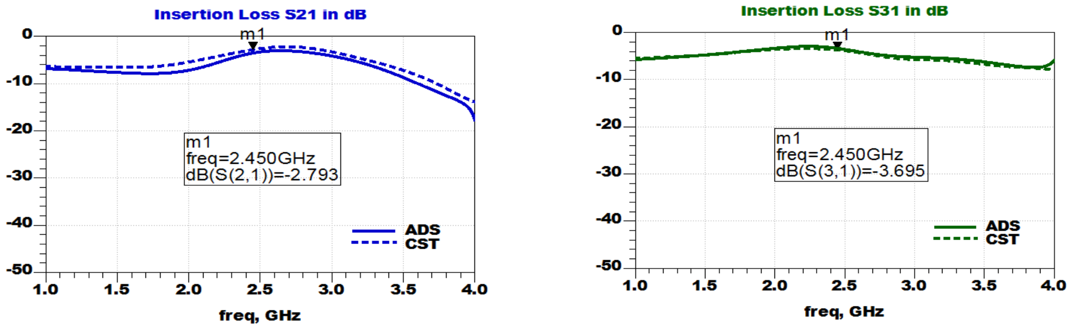
The simulated results of the reflection coefficient and isolation are shown in Figure 7 (a) and Figure 7(b), respectively. It’s well observed that a good matching and good isolation have obtained for the whole range of frequency from 2.2 up to 2.8 GHz.



(a) (b)

Figure 7. Simulated results, (a) reflection coefficient and (b) isolation.

The Figure 8 illustrates the simulated results of insertion loss as shown in Figure 8 (a) and coupled factor as shown in Figure 8 (b). As we can see, the both transmission coefficients are around -3dB at the center frequency of the operating band ISM.



(a) (b)

Figure 8. Simulated results, (a) insertion loss (S21) and (b) coupled factor (S31).

The Figure 9 shows the phase difference between the direct and coupled ports. The value of the phase difference is -87.51° at the resonance frequency of the ISM band.

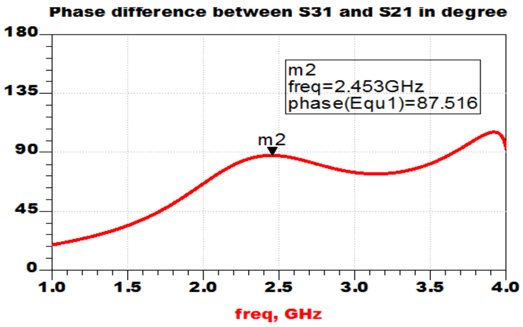


Figure 9. Simulated results of the phase difference between the direct and coupled port.

4. Fabrication and measurement results

The photograph of the prototype of proposed branch-line coupler shown in Figure 10 is achieved by using LPKF machine. This prototype is fabricated on printed-circuit board having dielectric constant of 4.4 and dielectric thickness of 1.58 mm. The S-parameters of the prototype are measured by an HP 8719ES vector network analyzer. In comparison with the simulated S-parameters, we would like to point out that the measured performance is slightly degenerated by not only the permittivity deviation of substrate but also the fabrication tolerance.

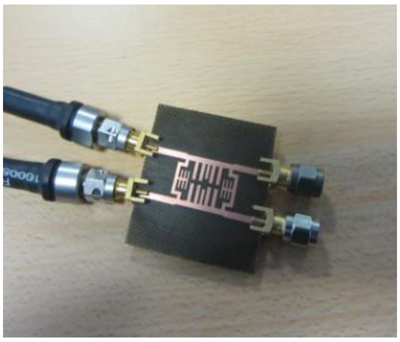
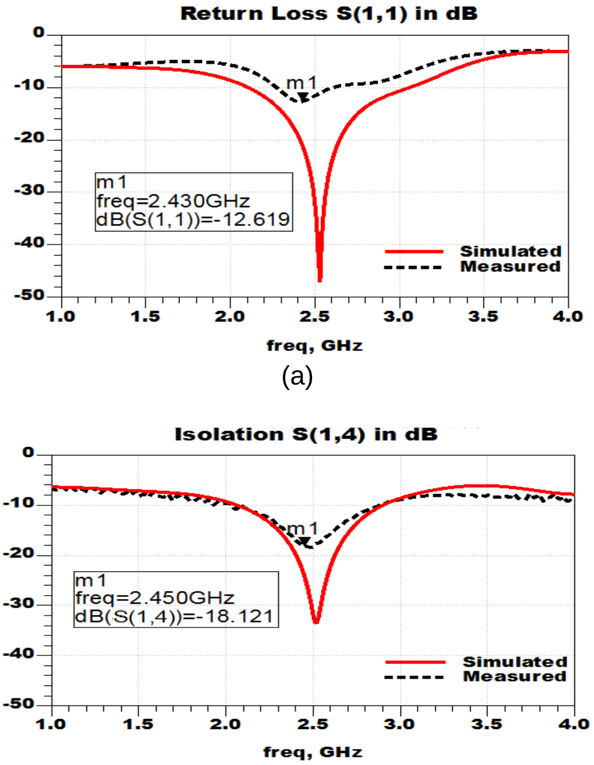


Figure 10. Photograph of the fabricated coupler.

The measured results of the reflection coefficient and isolation are depicted in Figure 11 (a) and Figure 11(b), respectively. It's well observed that reflection coefficient S11 is -12 dB, and coefficient of the isolation is -18.12 dB at the resonance frequency of the ISM band.

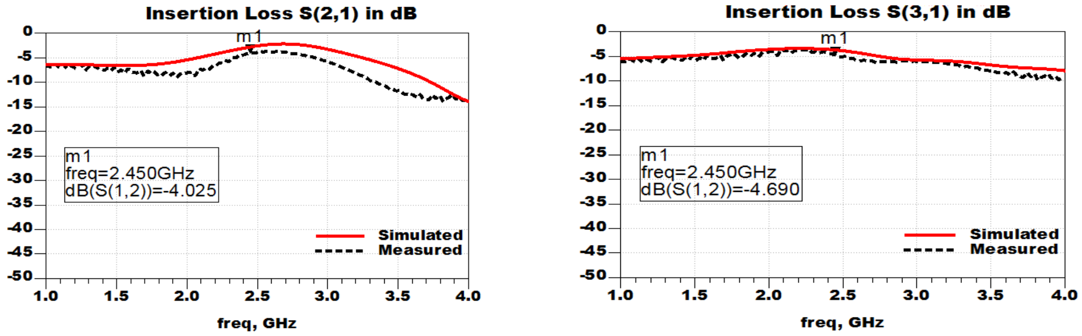


(a)

(b)

Figure 11. Measured results, (a) reflection coefficient and (b) isolation

The measured results of the transmission coeficients S21 and S31 are illustrated in Figure 12 (a) and Figure 12(b), respectively. For the both coefficients, the value around -3 dB is obtained for the whole bandwidth of ISM.



(a) (b)

Figure 12. Measured results , (a) insertion loss (S21) and (b) coupled factor (S31)

The phase difference measured between the output ports is depicted in Figure 13. The phase difference is 85.81° at the resonance frequency 2.45 GHz. Such value is acceptable for all receivers since ± 5° error is negligible and indicates good transmission percentage.

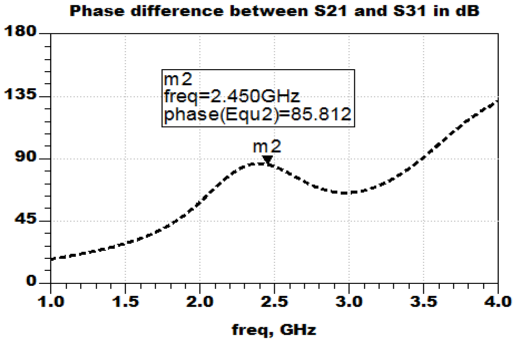


Figure 13. Measured results of the phase difference between the ouput ports.

The characteristics of the proposed coupler are demonstrated by the simulated as well as measured S-parameters of the fabricated prototype.

5. Conclusion

In this paper, a miniaturized compact microstrip branch line coupler is proposed and realized by using the planar resonators. At first, some design equations for the planar resonators are derived using the theory. Secondly, the proposed coupler was designed, simulated and fabricated at the frequency of 2.45 GHz for ISM applications. By implementing ADS Agilent technologies and CST studio software, the proposed coupler was etched on FR4 substrate. Good performrances are found in terms of the matching, isolation, insertion loss and phase difference. The size reduction of the proposed design is 50 % with comparable performance as that of the conventional branch line coupler. The ease of design using standard etching process makes the fabrication of the miniaturized coupler simpler and with low cost. Finally, this prototype can be integrated into the design of microwave or millimeter-wave integrated circuits where the compactness of components is crucial.

References

[1] Li, B., X. Wu, and W. Wu. A miniaturized branch-line coupler with wideband harmonics suppression. *Progress in Electromagnetics Research Letters*. 2010; 17: 181-189,

[2] Lopez-Berrocal, B., J. de-Oliva-Rubio, E. Marquez-Segura, A. Moscoso-Martir, I. Molina-Fernandez, and P. Uhlig. High performance 1.8-18 GHz 10-dB low temperature co-flred ceramic directional coupler. *Progress in Electromagnetics Research*. 2010; 104: 99-112.

[3] Li, X., S.-X. Gong, L. Yang, and Y.-J. Yang. A novel Wilkinson power divider for dual-band operation. *Journal of Electromagnetic Waves and Applications*. 2009; 23(2–3): 395-404.

[4] Chiang, C. T. and B.-K. Chung. Ultra wideband power divider using tapered line. *Progress In Electromagnetics Research*. 2010; 106:61-73.

[5] Zheng, N., L. Zhou, and W. Y. Yi. A novel dual-band Π-shaped branch-line coupler with steppedimpedance stubs. *Progress in Electromagnetics Research Letters*. 2011; 25:11-20.

[6] Pozar, D. M. Microwave Engineering. 3rd Edition. John Wiley & Sons, Inc., Hoboken, NJ. 2005.

[7] Zheng, S. and W. Chan. Differential RF phase shifter with harmonic suppression. *IEEE Trans. Ind. Elctron*. 2014; 61(6):2891-2899.

[8] N. Zheng, L. Zhou, and W.-Y. Yin. A novel dual-band shaped branch-line coupler with stepped-impedance stubs. *Progress in Electromagnetics Research Letters.* 2011; 25:11-20.

[9] Sami HEBIB. Nouvelle topologie d'antennes multi-bandes pour applications spatiale. L'Université Toulouse III. 2008

[10] M. Kazerooni and M. Aghalari. Size reduction andharmonic suppression of rat-race hybrid coupler using defected microstrip structure. *Progress in Electromagnetics Research Letters*. 2011; 26:87-96.

[11] Maas, S. A. Microwave Mixers. Artech House, Norwood, MA, 1986.

[12] S.-L. Zuo, Y.-Z. Yin, Z.-Y. Zhang, W.-J. Wu, and J.-J. Xie. Eigenmode decoupling for mimo loop-antenna based on 180° coupler. *Progress in Electromagnetics Research Letters*. 2011; 26:11-20.

[13] P .F. Combes. Circuits Passifs, Propagation, Antennes, 2nd ed. Dunod.Paris, 1997.

[14] Moubadir, M., H. Aziz, N. Amar Touhami, M. Aghoutane, K. Zeljami, and A. Tazon. Design and implementation of a technology planar 4× 4 butler matrix for networks application. *International Journal of Microwave and Optical Technology.* 2015; 10(6):446-451.

[15] Moubadir, M., H. Aziz, N. Amar Touhami, M. Aghoutane, K. Zeljami, and A. Tazon. *Design and implementation of a technology planar 8×8 butler matrix with square truncated edge-fed array antenna for WLAN networks application*. The International Conference on Wireless Networks and Mobile Communications. 2015.

[16] Jizat, N. M., S. K. A. Rahim, T. A. Rahman, and M. R. Kamarudin. Miniaturize size of dual band branch-line coupler by implementing reduced series arm of coupler with stub loaded. *Microwave and Optical Technology Letters*. 2011; 53(4).

[17] Wong, Y. S., S. Y. Zheng, and W. S. Chan. Multifolded bandwidth banch line coupler with filtering characteristic using coupled port feeding. *Progress in Electromagnetics Research*. 2011; 118:17-35.

[18] Liu, G. Q. and L. S. Wu. A compact microstrip rat-race coupler with Modified Lange and T-shaped arms. *Progress in Electromagnetics Research*. 2011; 115:509-523.

[19] Lu, K., G. M. Wang, C. X. Zhang, and Y. W. Wang. Design of miniaturized branch-line coupler based on novel spiral-based resonators. *Journal of Electromagnetic Waves and Applications*. 2011; 25(16):2244-2253.

[20] Yang, T., M. Tamura, and T. Itoh. Compact hybrid resonator with series and shunt resonances used in miniaturized filters and balun filters. *IEEE Trans. Microw. Theory Tech*. 2010; 58(2):390-402.

[21] A. Sardi, J. Zbitou, A. Errkik, L. Elabdellaoui, A. Tajmouati, M. Latrach. A Novel Design of A Microstrip 3dB Coupler. *International Journal of Microwave and Optical Technology*. 2014; 9(6).

[22] A. Sardi, J. Zbitou, A. Errkik, A. Tajmouati, H. Bennis, A. Mediavilla. A Novel Design of Dual-Band Coupler with Stepped-Impedance Open Stubs. *Praize worthy prize, International Journal on Communications Antenna and Propagation*. 2015; 5(6):2039-5086.

[23] A. Sardi, J. Zbitou, A. Errkik, L. Elabdellaoui, A. Tajmouati, M. Latrach, A. Tribak. A Novel Design of Miniature Coupler for WiMAX Applications. *International Journal of Microwave and Optical Technology*. 2016; 11(2).