ITM Web of Conferences **48**, 01002 (2022) https://doi.org/10.1051/itmconf/20224801002
ICCWCS 2022

A compact dual-band patch coupler design for modern wireless applications

Khadija Abouhssous[1*], *Asmaa* Zugari[2], and *Alia* Zakriti[1]

[1] Laboratory of Science and Advanced Technology, Department of Civil and Industrial Sciences and Technologies, National school of Applied Sciences, Abdelmalek Essadi University, Tetouan, Morocco
[2] Information and Telecommunication System Laboratory, FS, Abdelmalek Essadi University, Tetouan, Morocco

Abstract. This paper presents a compact rectangular patch hybrid coupler design which can be operated at dual resonant frequencies and is suitable for modern wireless applications. The dual-band functionality while maintaining practical compactness is achieved by introducing a series of parallel rectangular slots. The proposed design is optimized by the CST studio suite software and etched on the FR4 substrate. The good agreement between the simulated and measured frequency responses indicate that the presented coupler is capable of operating from 2.44 GHz to 3.1 GHz and from 5 GHz to 5.8 GHz, with fractional bandwidth of 24.44% and 14.8%, respectively, and a size reduction of 56.28%. The robust simulation results indicate that the proposed design is suitable for microwave integrated circuits (ICs) that require small size and dual functionality.

1 Introduction

The rapid development of wireless communications systems requires the creation of new systems that can operate in multiple frequency bands and support multiple standards. The multi-band RF components, consisting of single circuits and operating at multi-specified frequencies, are compact solutions for modern wireless communication systems. Therefore, the directional coupler [1], being an important passive device, must be redesigned to meet these requirements. These passive devices are widely used in various applications such as phase shifters [2], mixers, power amplifiers and bridging of many microwave circuits [3]. There are three main topologies for hybrid couplers. These are the branch line [4], coupled line [5] and patch line [6] structure. Each of these topologies has its specific benefits and drawbacks.

Various approaches have been suggested to design hybrid dual-band couplers. In reference [7] the authors have replaced the conventional coupler branches by a composite metamaterial transmission line on the right and left sides for dual-band functionality. The losses of the local components and interconnecting holes in the left-hand TLs are important. In [8], the cross-coupled branch coupler achieves the dual frequency band and improved frequency bandwidth by using the additional cross-coupled branches. The use of arms with connection lines was highly appreciated to ensure the implementation of a dual-band functionality and consequently, increase the overall surface of the couplers [9]. In Ref [10][5], dual-band performance is realized with the extension of ports and, as a consequence, increasing the coupler's total size. however, However, miniaturization is of particular interest for wireless equipment. Within this context, several works are oriented to realize dual-frequency structures while maintaining a compact size. For example, in [11], a dual-band inline coupler with reduced size is proposed by the authors, with a topology composed by two π-shaped TLs. In reference [12], the dual-band operation and miniature area are complemented by the use of non-uniform microstrip transmission lines. In addition, in reference [13], a dual-band miniature coupler with a power division of 3 dB is presented. This compact design is obtained through the folding of sections of the transmission line within a circuit. And in [14], the dual-band performance is achieved by implementing artificial transmission lines (TLs) based on open ring resonators (OSRRs).

This work presents the design, the simulation and the fabrication of a compact dual-band hybrid coupler with rectangular patch loaded by parallel rectangular slots as shown in Figure 1. Our proposed design has various benefits compared to conventional dual-band systems. First, the patch design minimizes the undesirable effects caused by junction discontinuity in the BLC design as the operating frequency rises. Second, the patch offers a structure which is simple, easily and inexpensively manufactured. Third, the rectangular slot-loaded hybrid patch coupler is able to offer a wider bandwidth than the branched line coupler-based designs. Finally, the slot-loaded rectangular patch hybrid coupler has a

* Corresponding author: abouhssoukhadija@gmail.com

convenient phase response at the output ports and can provide a quadrature phase difference in both bands. In this paper, a conventional single-band rectangular patch hybrid coupler is presented firstly, and then a compact-sized dual-band rectangular patch hybrid coupler topology is defined by introducing parallel rectangular slots.

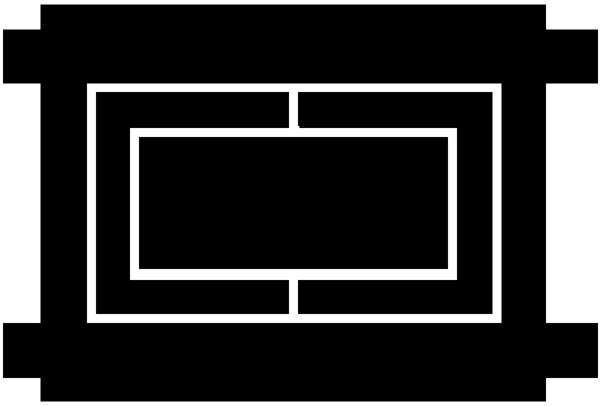

Fig.1. Design of the proposed dual-band coupler with rectangular patch

2 Conventional patch coupler

The design procedure starts by using the standard transmission line model equations as a guideline for the design of the conventional microstrip patch coupler, as shown in Figure 2. Through the adjustment of the center of the frequency band to 3.5 GHz and the properties of the material used, namely FR-4, the conventional patch coupler dimensions are achieved which are given in Table 1.

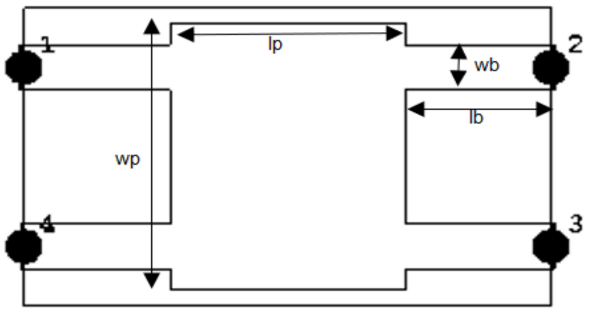

Fig. 2. Conventional patch coupler design

Table 1. Dimensions of the conventional patch coupler

Parameters	Value (mm)
wp	25.4
lp	21
wb	4.35
lb	13

The area occupied by the traditional patch coupler design is (25.4mm^{x}47mm). The Figure 3 and Figure 4 show the simulated frequency responses of the design, where the return loss$|S_{11}|$and isolation$|S_{41}|$ are 24.7 dB and 56.5 Db at the resonant frequency of 3.5 GHz respectively. Furthermore, the coupling factor $|S_{31}|$ and insertion loss $|S_{21}|$ are equal to 3.7 dB and 4.4 dB, respectively, with a phase difference of the output ports of 88.1°.

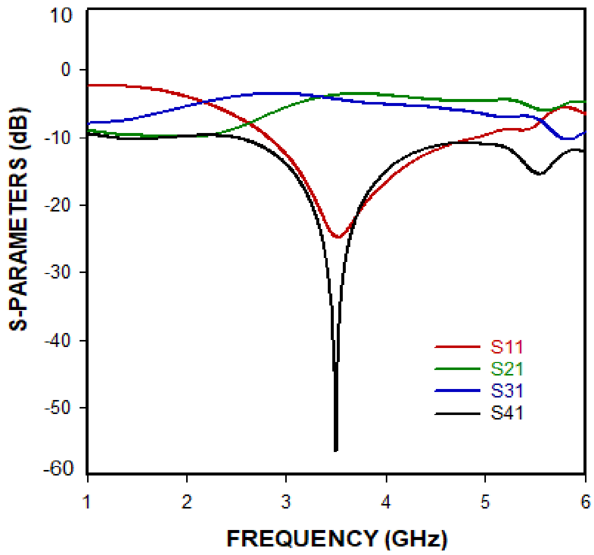

Fig.3. Conventional patch coupler frequency response

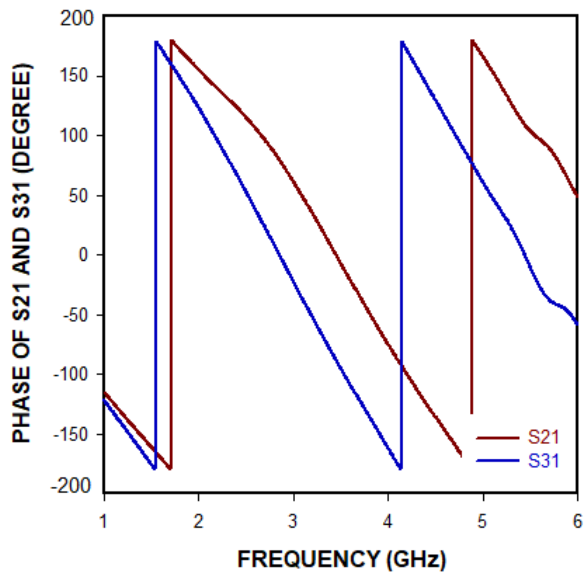

Fig.4. Two output ports phase of the conventional patch coupler

3 Compact dual-band patch coupler

To create dual-band functionality while simultaneously overcoming the bulky patch coupler size, a series of parallel rectangular slots have been etched on the patch, which introduces more resonances and achieves dual-band functionality characteristics. Figure 5 shows the dual-band hybrid coupler with rectangular patch, is simulated in an optimized way using CST studio suite software. The parameter dimensions used for this design

 https://doi.org/10.1051/itmconf/20224801002

are given in Table 2, of which the overall area of the proposed structure is (29mm*18mm), so it occupies 43.72% compared to the conventional structure, therefore it makes a saving of area by 56.28%.

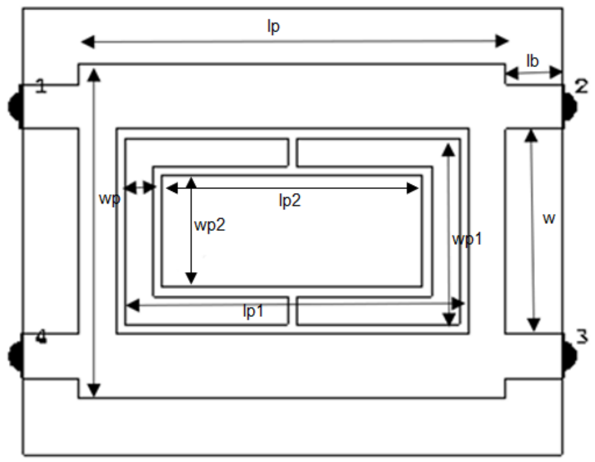

Fig.5. Proposed dual-band patch coupler design

Table 2. Dimensions of the proposed dual-band patch coupler

Parameters	Value (mm)
lp	23
wp	18
lp_1	19
wp_1	11
lp_2	16.5
wp_2	8.5
w	11
wb	2.4
lb	3
g	0.5

As shown in Figure 6, the proposed patch coupler has a good frequency response in two frequency bands. The return loss $|S_{11}|$, and the isolation $|S_{41}|$ are 46.6 dB, 25.4 dB at 2.6 GHz, and 22 dB, 31.6 dB at 5.3 GHz, respectively. And the simulated $|S_{21}|$, $|S_{31}|$ are 3.7 dB, 3.2 dB at 2.6 GHz, and 4.1 dB, 3.9 dB at 5.3 GHz, respectively. The fractional bandwidths with $|S_{11}| < 10$ dB and $|S_{41}| < 10$ dB are 36.15%, 33.42% at 2.6 GHz, and 16.79%, 20.94% at 5.3 GHz, respectively.

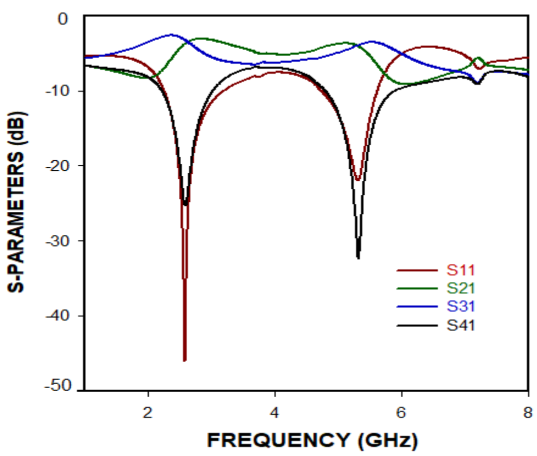

Fig.6. Proposed dual-band patch coupler frequency response

Figure 7 shows the simulated phase shifts between the two output ports. The phase differences are 88.4° and 92.7° respectively at the two reasoning frequencies.

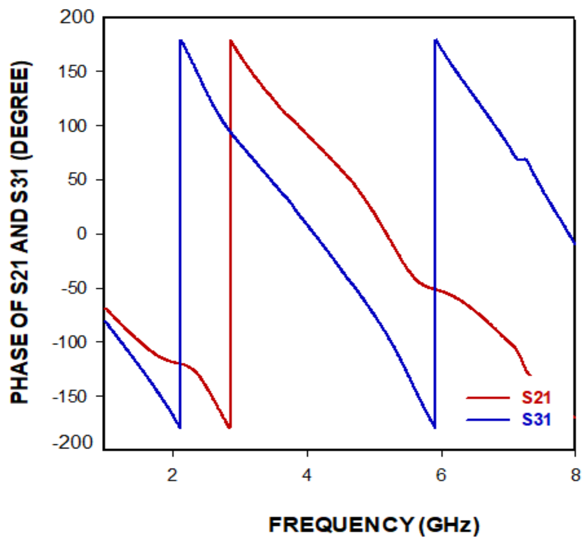

Fig.7. Phase of two output ports of the proposed dual-band patch coupler

Figure 8 shows the construction of the optimized hybrid quadrature coupler prototype, Where the dimensions of the miniature coupler are 29 mm*18mm, representing 56.28% of reduction compared to the conventional coupler. In Figure 9, the proposed design's frequency responses are shown, in which the manufactured construction demonstrates a strong match with the results of the simulation, so that the proposed coupler has two bandwidths ranging from 2.44 GHz to 3.1GHz and 5 GHz to 5.8 GHz respectively while keeping high performance. The phase difference measured between the two output ports S_{21} and S_{31} is equal to 88% for the 1st band centered at 2.72 GHz and 88.2% for the 2nd band centered at 5.4 GHz, indicating that the envisaged layout is adequate for connecting the signals diagonally for the two reasonable frequencies.

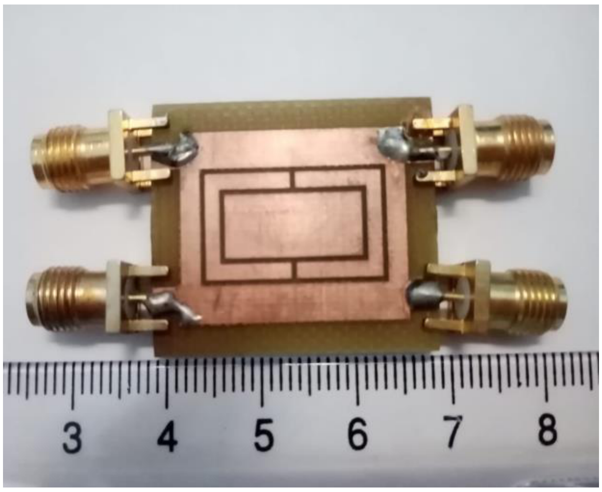

Fig. 8. Proposed dual-band patch coupler photograph

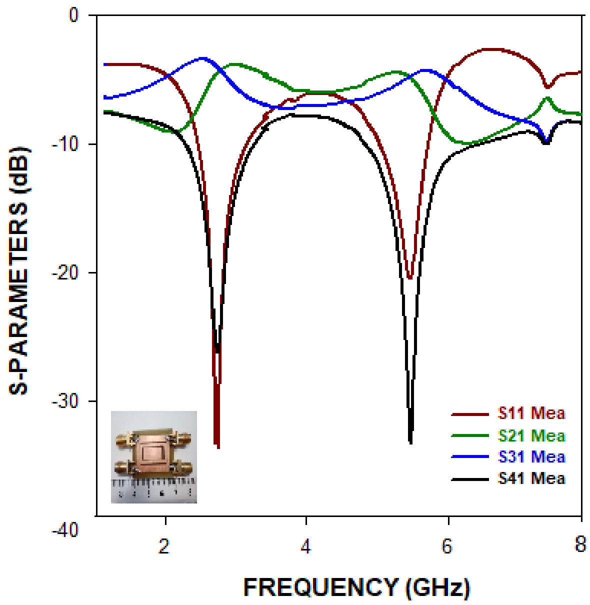

Fig.9. Frequency response of the manufactured dual-band patch coupler

4 Result and discussion

In this chapter, we compare the traditional coupler and the proposed design. The results of this comparison are shown in Table 3, which demonstrates that the proposed configuration provides a 56.28% size reduction over the conventional design. Simultaneously, the proposed structure provides dual-band behaviour while maintaining high performance. The high agreement of the proposed dual-band patch coupler's simulated and measured performance can be seen in Figures 10 and 11, and demonstrate the success of this structure in meeting the need for multiple standards and dual-band operation.

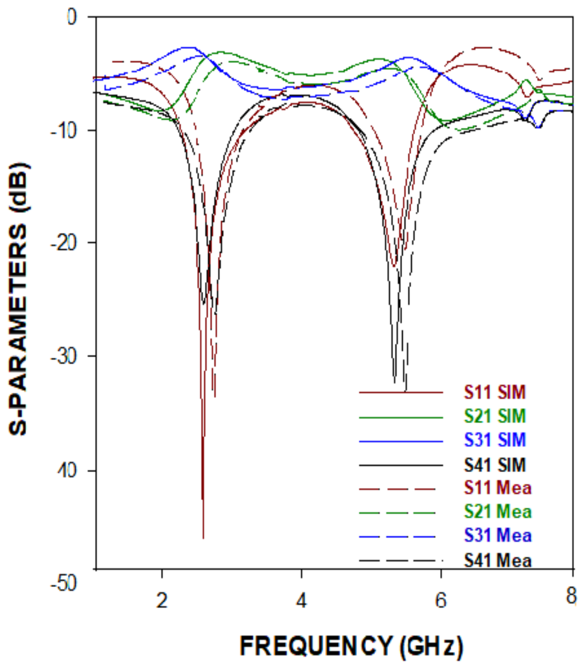

Fig.10. Proposed dual-band patch coupler simulation and measurement results

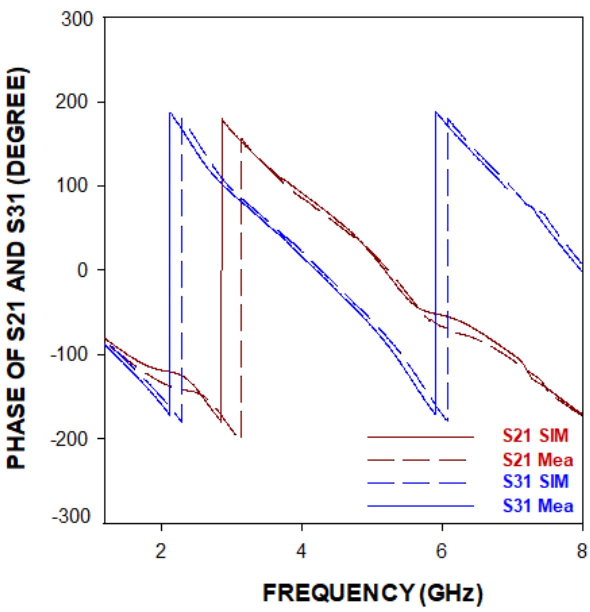

Fig.11. The proposed dual-band patch coupler simulation and measurement phase

Table 3. Comparison between the conventional and the proposed model of the dual-band patch coupler.

Parameters	Conventional Result	Simulation Result		Measurement Result	
Frequency (GHz)	3.5	2.6	5.3	2.72	5.4
$S_{11}(dB)$	-24.7	-46.6	22	-33.29	-20.13
$S_{21}(dB)$	-4.4	-3.7	4.1	-3.8	-4.5
$S_{31}(dB)$	-3.7	-3.2	3.9	-4	-4.5
$S_{41}(dB)$	-56.5	-25.4	31.6	-26.28	-33
Phase Difference (°)	88.1	88.4	92.7	88	88.2
FBW (%)	62	36.15	16.79	24.44	14.8
Area (mm^2)	25.4*47	29*18			
Percent reduction (%)	56.28%				

With the aim of properly evaluating the results of the envisaged coupler. A comparative study of the dual-band coupler presented here versus some others reported earlier in frequency response, phase shift and physical dimensions is given in Table 4. The encouraging results of the dual-band patch coupler indicate that it is a good choice for wireless communications systems, which require systems that can cover several bands and support several standards.

Table 4. Comparison between proposed coupler with previous works

Ref	Freq. (GHz)	$S_{11}(dB)$	$S_{21}(dB)$	$S_{31}(dB)$	$S_{41}(dB)$	D.P(°)	Size (mm^2)
[10]	1	-36.7	-3.3	-3.1	-32.9	90	33.66x32.34
	2	-25.3	-3.1	-3.7	-29.9	89.89	
[11]	0.87	-26	-3.3	-3.67	-34	89.3	31x31
	1.79	-21.6	-3.09	-3.9	19.9	91.4	
[12]	0.9	-18.3	-3.1	-3.25	-18.33	90	65.34x65.34
	1.8	-19.1	-3.08	3.14	-18.7	90	
This work	**2.6/2.72**	**-46.6/-33.29**	**-3.7/-3.8**	**-3.2/-4**	**-25.4/-26.28**	**88.4/88**	**29x18**
	5.3/5.4	**-22/-20.13**	**-3.9/-4.5**	**-4.1/-4.5**	**-31.68/-33**	**92.7/88.2**	

5 Conclusion

A miniature dual-band hybrid patch coupler has been presented. Parallel slots are used to achieve dual-band operation while maintaining a compact size and lower complexity. The simulation and optimization of the proposed hybrid patch coupler is performed by the CST studio simulation software and then etched on the FR-4 substrate. The results measured show the ability of the proposed structure to operate from 2.44 GHz to 3.1 GHz and from 5 GHz to 5.8 GHz, with a size of (29mm x 18mm). The scattering parameter and output port phase difference results have excellent performance and high agreement between measurement and simulation results, showing that this coupler prototype is well suited to modern wireless implementations that require dual-band operation and a compact size.

References

1. Zaidi, Aijaz M., Mirza Tariq Beg, Binod Kumar Kanaujia, Karun Rawat, Sachin Kumar, Karumudi Rambabu, Satya P. Singh, et Aimé Lay-Ekuakille. « A Dual-Band Rat-Race Coupler for High Band Ratio Wireless Applications ». IEEE Transactions on Instrumentation and Measurement 70 (2021)
2. Liu, Hongmei, Xuejiao Wang, Tielin Zhang, Shao-Jun Fang, et and Zhongbao Wang. « Design of Full-360° Reflection-Type Phase Shifter Using Trans-Directional Coupler with Multi-Resonance Loads ». Progress In Electromagnetics Research Letters 101 (2021)
3. Shao, Qiang, Fu-Chang Chen, Yi Wang, et Qing-Xin Chu. « Design of 4 × 4 and 8 × 8 Filtering Butler Matrices Utilizing Combined 90° and 180° Couplers ». IEEE Transactions on Microwave Theory and Techniques 69, no 8 (août 2021)
4. Roshani, Sobhan, et Saeed Roshani. « A Compact Coupler Design Using Meandered Line Compact Microstrip Resonant Cell (MLCMRC) and Bended Lines ». Wireless Networks 27, no 1 (1 janvier 2021)
5. Islam, Rakibul, Asif I. Omi, Mohammad A. Maktoomi, Christine Zakzewski, et Praveen Kumar Sekhar. « A New Coupled-line Based Dual-band Branch-line Coupler With Port-Extensions ». Progress In Electromagnetics Research M 105 (2021)
6. Liu, Jia, Yongqiang Wang, et Kaixue Ma. « A Compact Folded Patch Coupler Based on SISL Platform ». IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP), 323-25, 2021.
7. Lin, Xian Qi, Ruo Peng Liu, Xin Mi Yang, Ji Xin Chen, Xiao Xing Yin, Qiang Cheng, et Tie Jun Cui. « Arbitrarily dual-band components using simplified structures of conventional CRLH TLs ». IEEE Transactions on Microwave Theory and Techniques 54, no 7 (juillet 2006)
8. Collado, C., A. Grau, et F. De Flaviis. « Dual-band planar quadrature hybrid with enhanced bandwidth response ». IEEE Transactions on Microwave Theory and Techniques 54, no 1 (janvier 2006)
9. B. Li, W. Wu. « Compact Dual-Band Branch-Line Coupler with Power Dividing Ratio» Journal of Electromagnet: Waves and Applications;25(4):607–15(2011)
10. Kim, Hyunchul, Byungje Lee, et Myun-Joo Park. « Dual-Band Branch-Line Coupler With Port Extensions ». IEEE Transactions on Microwave Theory and Techniques 58, no 3 (mars 2010)
11. Gai, Chao, Yong-Chang Jiao, et Yu-Long Zhao. « Compact Dual-Band Branch-Line Coupler With Dual Transmission Lines ». IEEE Microwave and Wireless Components Letters 26, no 5 (mai 2016)
12. Taravati, S., et M. Khalaj-Amirhosseini. « Compact Dual-band Stubless Branch-line Coupler ». Journal of Electromagnetic Waves and Applications 26, no 10 (1 juillet 2012)
13. A. Bekasiewicz and S. Koziel. « Miniaturised Dual-band Branch-line Coupler» Electronics Letters - Wiley Online Library ; Vol. 51 No. 10 pp. 769–77(2015
14. Ghaffarian, Mohammad Saeid, Gholamreza Moradi, et Pedram Mousavi. « Dual band/ Dual Mode Branch-Line/Rat-Race Coupler Using Artificial Transmission Line ». In 2019 27th Iranian Conference on Electrical Engineering (ICEE), 1622-26, (2019).