

MINIATURIZATION OF BRANCH-LINE COUPLERS USING OPEN STUBS AND STEPPED IMPEDANCE UNIT CELLS WITH MEANDERING TRANSMISSION LINES

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ABSTRACT

In this paper, two proposed structures of the compact Branch-Line Couplers BLCs are designed and simulated. Three different technologies of miniaturization BLC are used together, open ended stubs, meandering transmission lines, and stepped impedance. The results of the two designed BLC are compared to previously published results work at the same frequency 1.8GHz, the two proposed structures are designed and simulated using CST full wave simulator. The first and second structures are occupied only 61.8% and 50.8%, respectively, from the area of the conventional design. The paper presents a comparative study between simulated results of the two proposed designs and the measured results, the results show good agreement especially in the stepped impedance BLC.

KEYWORDS

Branch-Line Couplers BLCs, open ended stubs, meandering transmission lines, stepped impedance.

1.INTRODUCTION

Branch-line coupler is a passive microwave device used in the many communication systems, such as power dividers, power combiners, balance amplifiers, and balance mixtures. BLC is also known as a 3dB quadrature hybrid coupler. It has two main transmission lines with characteristic impedance $Z_0/\sqrt{2}$, and two shunt transmission lines with characteristic impedance Z_0 . As shown in Figure. 1, the area of the device is $\lambda/4 \times \lambda/4$, which occupies large space in the low frequency range [1, 2], hence the size reduction of the BLC becomes an important issue. The dimension of the device depends mainly on the operating frequency, so that at low frequencies the size of the BLC becomes very large, and not suitable to fabricate by PCB planner micro strip technology. There are many techniques have been used to solve the size problem for the conventional BLC, the most popular techniques are using stepped impedance [3] – [5], using stubs on the transmission line [6] – [9], meandering transmission line [10] and using lumped components in conjunction with high-impedance transmission lines [11, 12].

In this paper, we focus on the miniaturization of BLC, with maintaining the performance of the device. The strategy is based on design one unit cell of the open ended stub which is extensively presented in [9], the first proposed structure of the compact BLC based on using open stubs and meandering transmission lines, and the second one is based on using open stubs and stepped impedance unit cells. The two proposed structures of the BLC are designed and simulated using CST full wave EM simulator [13]. The optimum structure design is compared to the previously published measured result [8]. The comparison shows very good agreement between both results. All of the proposed BLCs are designed to operate at 1.8GHz, which is suitable for GSM 1800 application.

The paper is organized as follows: section II discusses the size reduction of the BLC using open ended stubs, Section III design, compact BLC using open ended stub unit cells and meandering TL, Section IV design, compact BLC using stepped impedance unit cells and meandering TL, followed by the conclusion and relevant references.

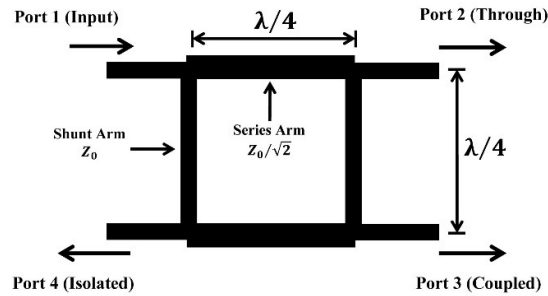


Figure 1. Conventional branch-line coupler.

2. MINIMIZE THE CIRCUIT AREA OF THE BLC USING OPEN ENDED STUB UNIT CELLS

Many studies have been presented to reduce the size of the BLC, can be classified into two main categories: classical and new techniques. In this paper, we will discuss some of the classical techniques, and the new techniques based on the advanced materials (e.g. metamaterials, HTS, and ferroelectric) are not covering here. In the classical methods, the size reduction can be done using lumped components in conjunction with high-impedance transmission lines, meandering transmission lines of the structure, using stepped impedance, and using both short and open ended stubs to represent distributed inductors and capacitors.

The open ended stubs are positioned on the conventional transmission line TL to make load capacitance which is lead to the small size of the modified TL, the derivation of the design equations are presented in [9], Figure. 2 (a), shows one unit cell of the design, l_{TL} , W_{TL} , represent the length and the width of the unit cell, respectively, l_{Stub} , W_{Stub} represent the length and the width of the open stub unit cell, respectively. Fig.2 (b) depicts the Branch-line coupler with open ended stubs. Table 1, shows the design specification of the one unit cell of the open ended stubs BLC.

Table 1, design specifications of the open ended stubs BLC.

$Z_{OSTL} = 35 \ \Omega$		$Z_{OSTL} = 50 \ \Omega$
N	5	5
w_{TL} (mm)	1.9	1.3
l_{TL} (mm)	3.6	4.2
w_{stub} (mm)	1.8	2
l_{stub} (mm)	6.7	3.7

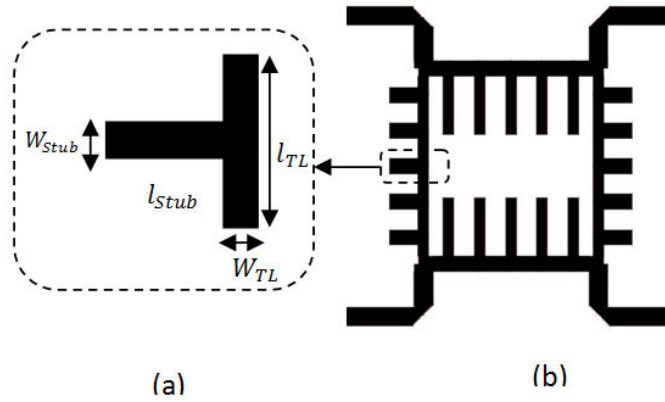


Figure 2. (a) One unit cell (b) Branch-line coupler with open ended stubs.

The dimension of a conventional BLC occupy large area, according to the length of the TL which is always $\lambda/4$ of the operating frequency, λ is so long at low frequencies range. When we use open ended stubs the dimension of the new BLC is reduced compared to the conventional design at the same dielectric substrate ($\epsilon_r = 2.2$) and thickness ($h = 0.7874$ mm) to works at frequency 1.8 GHz. Figure 3, shows comparison between two designs, red line for conventional design and black lines for open ended stubs design with different number of stubs (N) from (1 - 10), as shown in this figure, at frequency range (1-2 GHz) there are a good size reduction in the design area of the open ended stubs BLC, at the operating frequency 1.8 GHz the design area is reduced from 11 cm^2 (conventional BLC) to 7.17 cm^2 (open stubs BLC) [9].

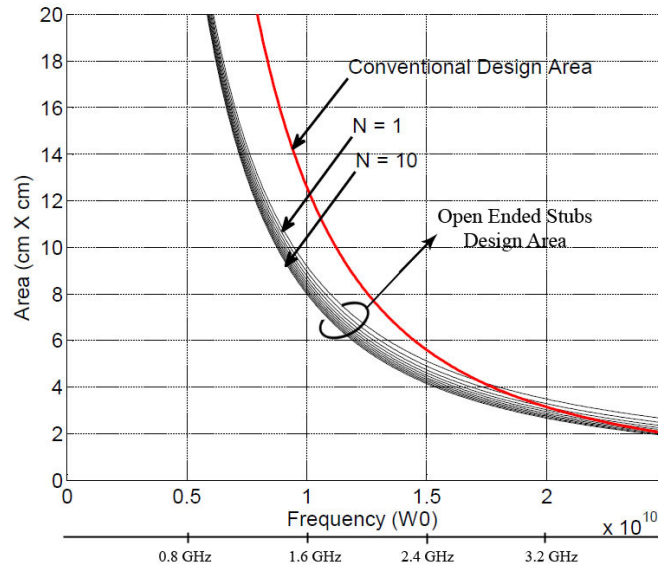


Figure 3. Comparison between the design area cm^2 of the open ended stubs and conventional BLC.

The performance of the two designs are presented in the Figure 4, and summarized in Table 2, which shows open stubs BLC with different number of stubs (e.g. 2, 5, and 8). When the number of stubs $N=5$ (grey shadow column), the open ended stubs BLC gives an optimum performance, the return loss (S_{11}) and isolation (S_{14}) is about -35dB and -37dB respectively, and $S_{12}=S_{13}= -3$ dB, that means the signal output is divided equally through the two output ports. However, this performance is stable only in the narrow bandwidth, about (130 MHz), and the design area of the structure is reduced from 11 cm^2 to 7.17 cm^2 .

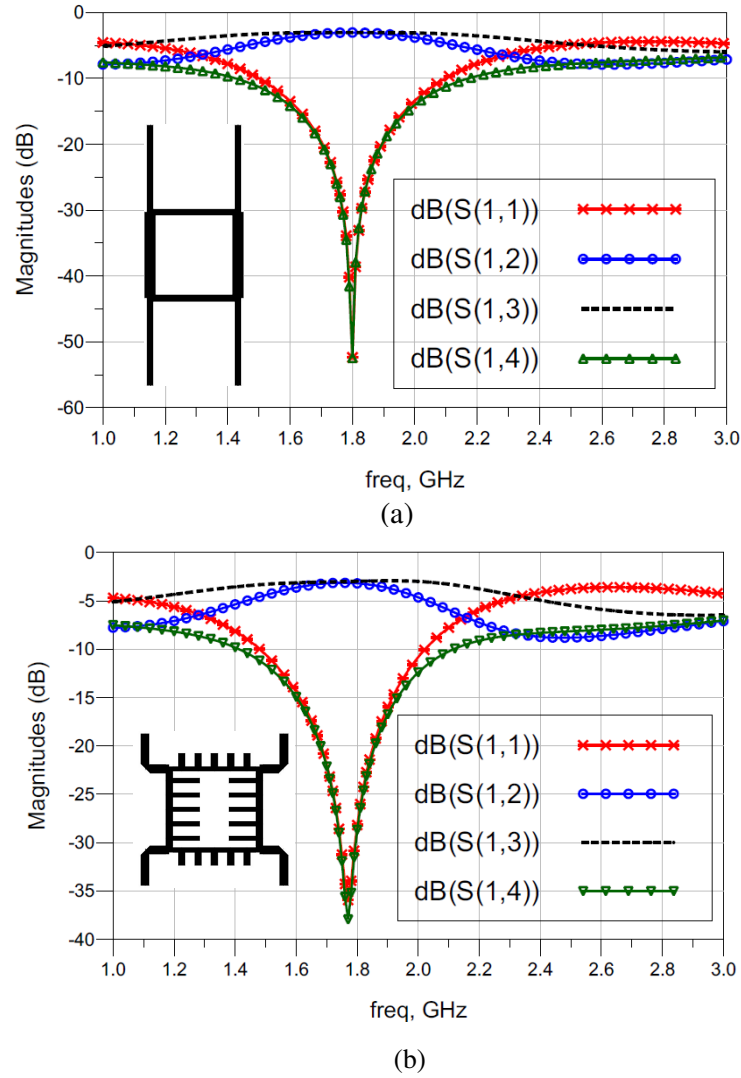


Figure 4. Magnitudes of the scattering parameters for the conventional BLC (a), and open stubs BLC (b).

Table 2, Comparison the performance of the open ended stubs (in case of N=2, 5, and 8) , and conventional BLC.

Open Ended Stubs Design				Conventional Design
N	2	5	8	0
f_0 GHz	1.75	1.77	1.77	1.8
(S11) dB @ f_0	-21.8	-35.9	-28.9	-52
(S14) dB @ f_0	-22.9	-37.9	-30	-52
(S12) dB @ f_0	-2.8	-3.1	-2.9	-3
(S13) dB @ f_0	-3.5	-3	-3.2	-3
BW MHz @ -15dB	280	130	314	320
BW %	15.5 %	7.2%	17.4%	17.7%
Design Area (cm^2)	7.3	7.17	6.5	11

3. SIZE REDUCTION OF THE BLC USING OPEN ENDED STUBS AND MEANDERING TRANSMISSION LINES

In the previous structure of the BLC, open ended stubs are placed on the both (main, and shunted) transmission lines, and in this structure that shown in Figure. 5, the open ended stubs are placed only on the main transmission line, but the shunt transmission line was meandered inside the free space of the BLC to achieve more small size. The design parameters of the structure are explained in Table 3.

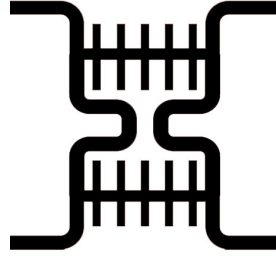


Figure 5. Branch-line coupler with open stubs unit cells and meandering transmission line

Table 3, Design specifications of the proposed structure BLC based on open ended stubs unit cell, and meandering lines ($\epsilon_r = 2.2$, $h=0.7874$ mm).

Main TL (open stub unit cells), $Z_0 = 35 \Omega$		Shunt TL (meander lines), $Z_0 = 50 \Omega$	
N	5	TL width	2.4 mm
w_{TL}	1.9 mm	TL length	31 mm
l_{TL}	3.7 mm		
w_{stub}	1.3 mm		
l_{stub}	9 mm		

The proposed BLC Figure. 5, is designed and simulated by CST, the design is compared to the previous published work [8], and conventional BLC designed on the same substrate ($\epsilon_r = 2.2$, $h=0.7874$ mm), and frequency work 1.8GHz. Figure. 6, shows the scattering parameters of the three structures, Table 4, shows comparative study between the performances of the three different designs. The proposed BLC shows very good size reduction compared to the conventional design, also the bandwidth of the proposed BLC is up to 312 MHz, where the bandwidth of the previous published BLC [8] is up to 300 MHz, and the conventional design is up to 338 MHz.

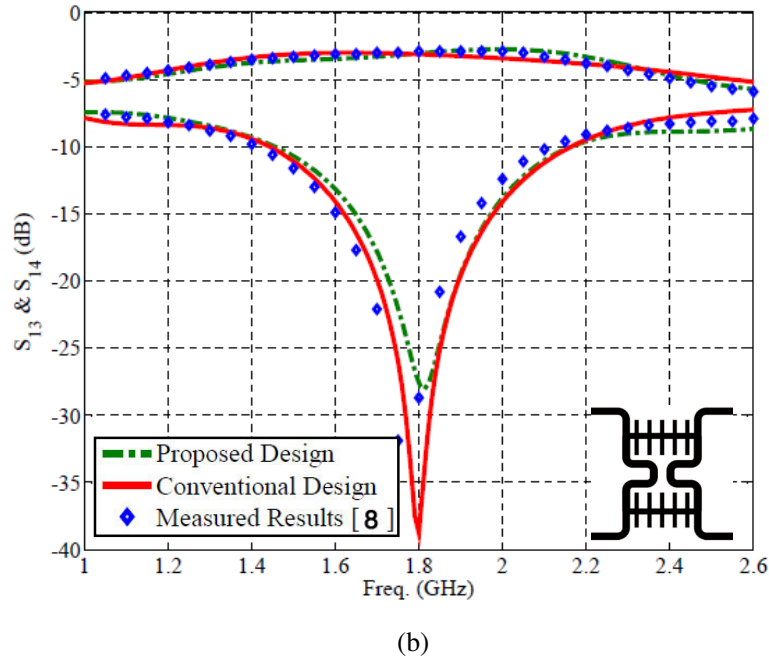
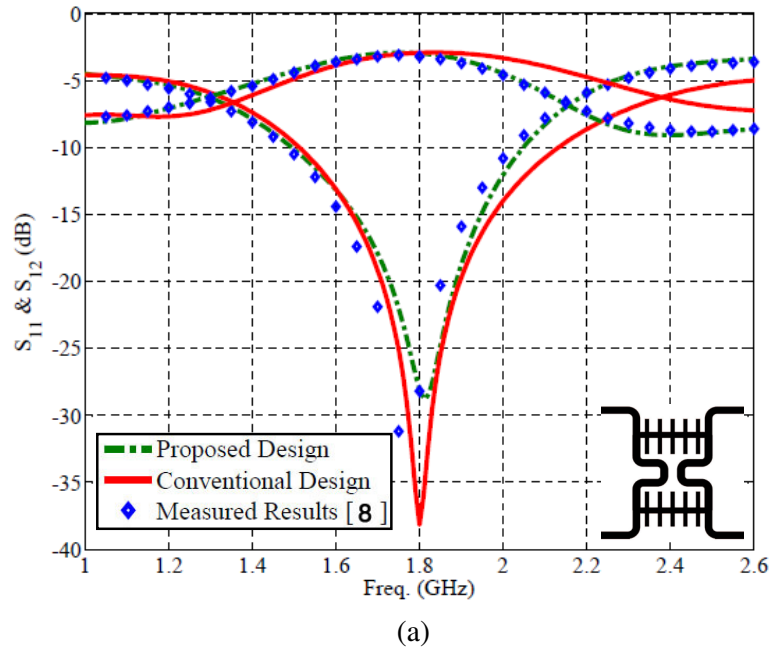


Figure 6. Comparison between S-parameters, magnitude of the proposed design (simulated by CST), conventional design (simulated by CST), and measured results [8], (a) for the magnitudes of (S_{11} , S_{12}), and (b) for the magnitudes of (S_{13} , S_{14}).

Table 4, Performance comparison for the three BLC types, proposed BLC based on open stubs and meandering TL, measured results [8], and conventional BLC.

Parameters	Proposed Design	Measured results [8]	Conventional BLC
Center Freq.(GHz)	1.8	1.75	1.8
(S ₁₁) dB @ f ₀	-27.8	-31	-38
(S ₁₄) dB @ f ₀	-27.9	-31.9	-38
(S ₁₂) dB @ f ₀	-3	-3.1	-2.9
(S ₁₃) dB @ f ₀	-3	-3	-3.1
Bandwidth (MHz)	312	300	338
Percentage (%) of Bandwidth @ S ₁₁ = -15dB	17.8%	16.7%	18.9%
Design Area cm ²	7.6 cm ²	6.87 cm ²	12.3 cm ²

4. SIZE REDUCTION OF THE BLC USING STEPPED IMPEDANCE AND MEANDERING TRANSMISSION LINES

Open ended stub unit cells sometimes take place inside and outside of the BLC circuit area, as shown in Figure 5, and occupies large space, for this reason the open ended stub unit cells have been transformed into the stepped impedance unit cells, which will be suitable and take less space than the open ended stub unit cells. Figure. 7 (a), shows one unit cell of the open ended stub, where, θ_{01} , and Z_{01} represent the electrical length and characteristic impedance, respectively, of the open ended stub unit cell. Figure. 7 (b), shows one unit cell of the stepped impedance, where, θ_{011} , and Z_{011} represent the electrical length and characteristic impedance, respectively, for the lower section of the stepped impedance unit cell, θ_{012} , and Z_{012} represent the electrical length and characteristic impedance, respectively, for the upper section of the stepped impedance unit cell.

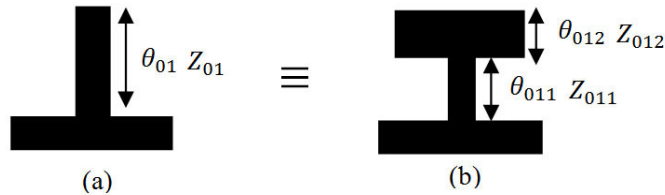


Figure 7. (a) One unit cell of the open stub (b) One unit cell of the stepped impedance.

The input impedance of the Figure 7. (a), is given by [2]:

$$Z_{in_a} = -j \frac{Z_{01}}{\tan(\theta_{01})} \quad (1)$$

And the input impedance of the Figure 7. (b) is given by:

$$Z_{in_b} = -jZ_{011} \frac{Z_{012} - Z_{011} \tan(\theta_{011}) \tan(\theta_{012})}{Z_{011} \tan(\theta_{012}) + Z_{012} \tan(\theta_{011})} \quad (2)$$

When we apply the equality between equation (1) and (2) we get:

$$\theta_{012} = \tan^{-1} \left[\frac{K \tan(\theta_{01}) - MK \tan(\theta_{011})}{M + \tan(\theta_{011}) \tan(\theta_{01})} \right] \quad (3)$$

Where, $K = Z_{012}/Z_{011}$, and $M = Z_{01}/Z_{011}$, Figure. 8, shows the relationship between the total length of the stepped impedance ($\theta_{011} + \theta_{012}$) in (mm) and ($M = Z_{01}/Z_{011}$), with different values of ($K = Z_{012}/Z_{011}$), from equation (3) we can calculate the value of (θ_{012}), however, only two parameters are given from open stub unit cell (θ_{01} and Z_{01}), the optimum values of the un known parameters can be selected from the plots shown in (Fig. 8, 9, and 10), the total length of the stepped impedance is inversely proportional to the value of (K), to get small length of the stepped impedance we must chose small values of (K) and (M).

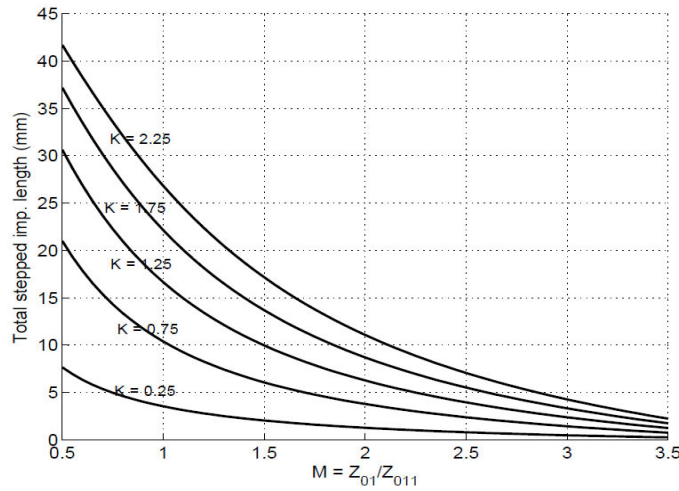


Figure 8. Relation between total length of the stepped impedance ($\theta_{011} + \theta_{012}$) in (mm) and (M) with different values of (K).

Figure. 9, depicts the relationship between the upper (θ_{012}), and the lower (θ_{011}) section of the stepped impedance unit cell with different values of (K), the electrical length (θ_{012}) is changes slightly with electrical length (θ_{011}), especially when the value of (K) is small, and the electrical length of the lower section (θ_{011}) of the stepped impedance must be taken precisely, to avoid coupling between the upper section (θ_{012}) of the stepped impedance unit cells and the main transmission line, also we can take equal lengths for the lower and upper sections, as in our design case is (e.g. $\theta_{011} = \theta_{012} = 2.3$ mm).

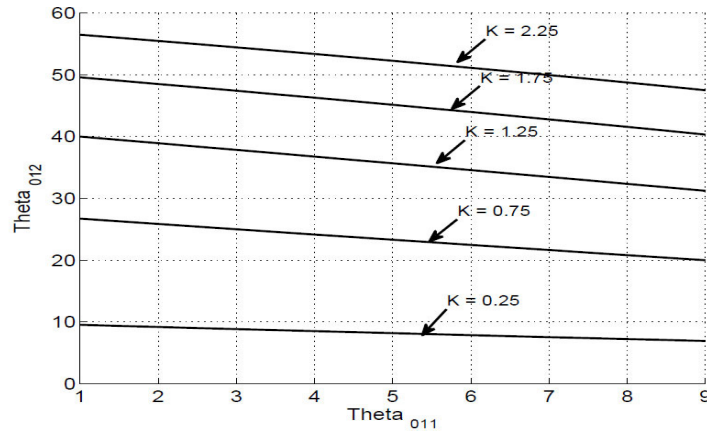


Figure 9. Relation between upper (θ_{012}) and lower (θ_{011}) sections of the stepped impedance unit cell, with different values of (K).

Figure 10, shows the relationship between (Z_{011} , and Z_{012}), with different values of (M), the characteristic impedance of the lower section (Z_{011}) must be very high impedance than the upper section (Z_{012}), also we observe that, the upper section (Z_{012}) characteristic impedance increases with increasing the lower section (Z_{011}) characteristic impedance.

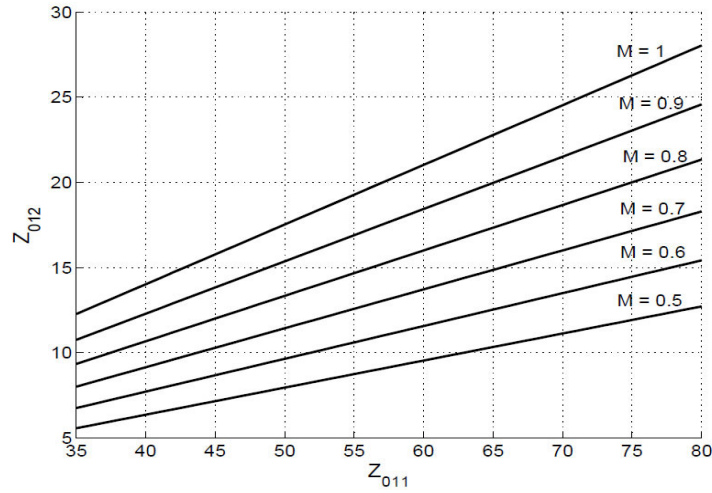


Figure 10. Relation between the characteristic impedance of the upper (Z_{012}) and lower (Z_{011}) sections of the stepped impedance unit cell, with different values of (M).

According to the above consideration, a new proposed BLC composed of stepped impedance unit cells and meandering TL is designed, as shown in Figure. 11, the stepped impedance unit cells are used instead of conventional TL with impedance $Z_0 = 35 \Omega$, while the other TL is meandered inside the free space of the BLC, Table5, shows the design specification.

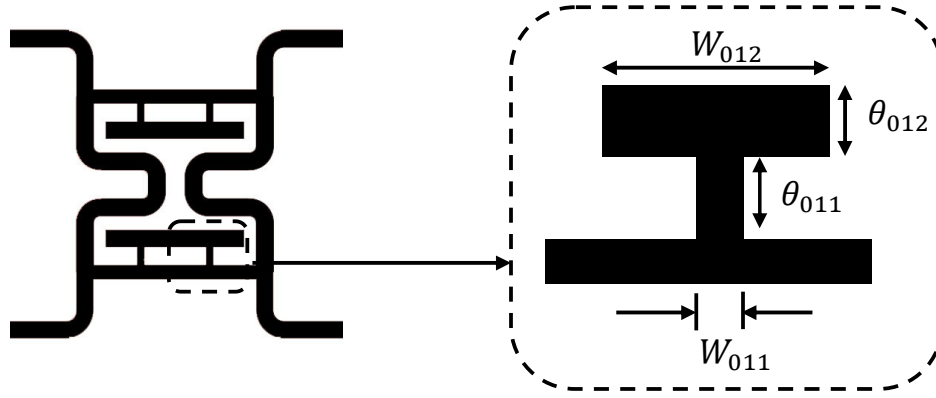
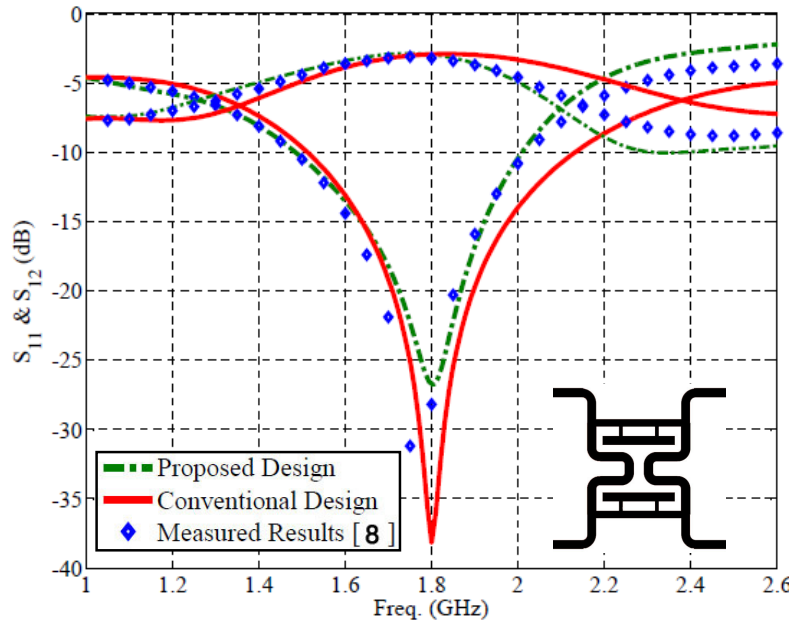


Figure 11. Branch-line coupler with stepped impedance unit cells and meandering transmission lines.

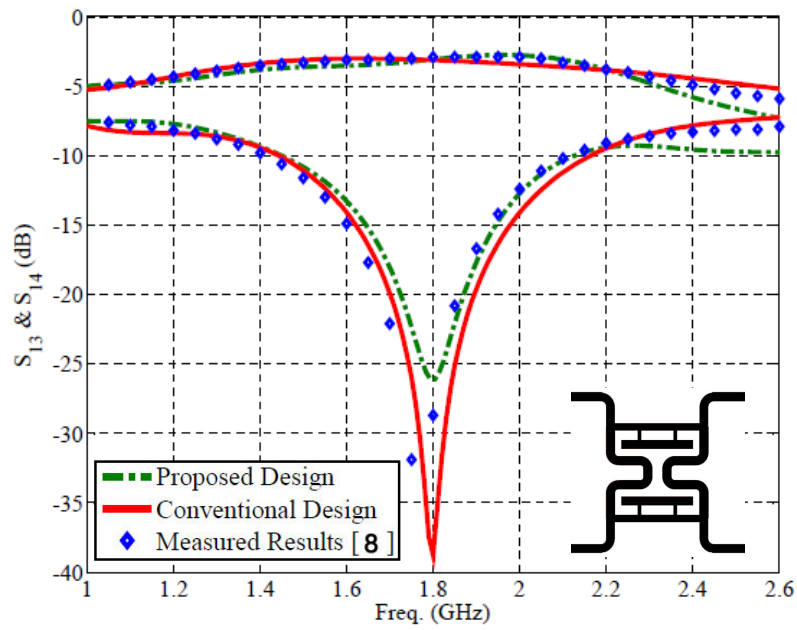
Table 5, Design specifications of the proposed structure BLC based on stepped impedance unit cell, and meandering lines ($\epsilon_r = 2.2$, $h=0.7874$ mm).

Main TL (stepped impedance unit cells), $Z_0 = 35 \Omega$		Shunt TL (meander lines), $Z_0 = 50 \Omega$	
Upper side section length θ_{012}	2.3 mm	TL width	2.4 mm
Upper side section width W_{012}	9 mm	TL length	31 mm
Lower side section length θ_{011}	2.3 mm		
Lower side section width W_{011}	1 mm		

The proposed BLC shows in Figure. 11, is based on stepped impedance and meandering TL, the structure is designed and simulated by CST, the proposed design is compared to the previous published results [8], and conventional BLC; designed on the same substrate ($\epsilon_r = 2.2$, $h=0.7874$ mm), and frequency work 1.8GHz, as shown in Figure. 12, the scattering parameters of the three structures show good agreement, Table 6, shows comparative study between the performances of the three designs, the return loss (S_{11}) and isolation (S_{14}) of the proposed BLC is about -26.7 dB and -26.1 dB respectively, and $S_{12}=S_{13}= -3$ dB, that means the signal output is divided equally through the two output ports, also the proposed BLC shows the smallest design area compared to the conventional design and the previous published BLC [8], and the bandwidth of the proposed BLC is about 275 MHz.



(a)



(b)

Figure 12. Comparison between S-parameters, magnitude of the proposed design (simulated by CST), conventional design (simulated by CST), and measured results [8], (a) for the magnitudes of (S_{11} & S_{12}) and (b) for the magnitudes of (S_{13} & S_{14}).

Table 6, Performance comparison of the three BLC types, proposed BLC based on stepped impedance and meandering TL, measured results [8], and conventional BLC.

Parameters	Proposed Design	Measured results [20]	Conventional BLC
Center Freq.(GHz)	1.8	1.75	1.8
(S_{11}) dB @ f_0	-26.7	-31	-38
(S_{14}) dB @ f_0	-26.1	-31.9	-38
(S_{12}) dB @ f_0	-2.9	-3.1	-2.9
(S_{13}) dB @ f_0	-3	-3	-3.1
Bandwidth (MHz)	275	300	338
Percentage (%) of Bandwidth @ $S_{11} = -15dB$	15.3%	16.7%	18.9%
Design Area cm^2	6.25 cm^2	6.87 cm^2	12.3 cm^2

5. CONCLUSIONS

Miniaturization of the branch-line coupler BLC have been studied, two new compact structures of the BLC were designed and simulated, the performance of the two designs show good agreement when compared to the previously published results and conventional BLC on the same substrate.

In the first structure, open ended stub unit cells with meandered TL have been used to design compact BLC, the proposed design shows good size reduction when compared to the conventional design, and occupies only 61.8% area of the conventional design, also the bandwidth of the proposed BLC is up to 312 MHz, where the bandwidth of the previous published BLC [8] is up to 300 MHz, and the conventional design is up to 338 MHz.

In the second structure, stepped impedance unit cells with meandered TL have been used to design compact BLC, the proposed design shows the smaller design area when compared to the conventional design, and occupies only 50.8% area of the conventional design, but the bandwidth of the proposed BLC is decreased to 275 MHz.

REFERENCES

- [1] Chang K., RF and Microwave Wireless Systems (2000), John Wiley & Sons, chapter 4.
- [2] Pozar D. M., Microwave Engineering (2012), John Wiley & Sons, chapter 7.
- [3] Choi, K.-S., Yoon, K.-C., Lee, J.-Y., Lee, C.-K., Kim, S.-C., Kim, K.-B. and Lee, J.-C. (2014), Compact branch-line coupler with harmonics suppression using meander T-shaped line. *Microw. Opt. Technol. Lett.*, 56: 1382–1384. doi: 10.1002/mop.28331.
- [4] Hee-Ran Ahn and Sangwook Nam, (2013) “Compact Microstrip 3-dB Coupled-Line Ring and Branch-Line Hybrids with New Symmetric Equivalent Circuits,” *IEEE Trans. Microwave Theory Tech.* 61, 1067–1078.
- [5] Kuo-Sheng Chin, Ken-Min Lin, Yen-Hsiu Wei, Tzu-Hao Tseng and Yu-Jie Yang, (2010) “Compact Dual-Band Branch-Line and Rat-Race Couplers with Stepped-Impedance-Stub Lines,” *IEEE Trans. Microwave Theory, Tech.* 58, 1213 – 1221.
- [6] A. Hazeri, A. Kashaninia, T. Faraji, and M. Arani, (2011) “Miniaturization and Harmonic Suppression of the Branch-line Coupler Based on Radial Stubs,” *IEICE Electronics Express*, vol. 8, no. 10, 736-741.
- [7] Ching-Wen Tang and Ming-Guang Chen, (2009) “Design of Multipassband Microstrip Branch-Line Couplers With Open Stubs,” *IEEE Trans. Microwave Theory Tech.* 57, 196 – 204.
- [8] Kimberley W. Eccleston, and Sebastian H. M., (2003) “Compact Planar Microstrip line Branch-Line and Rat-Race Couplers,” *IEEE Trans. Microwave Theory, Tech.* 51, 2119 – 2125.
- [9] Siddig Gomha, EL-Sayed M. El-Rabaie, and Abdel Aziz T. Shalaby, (2013) “Optimizing the Performance of Branch-line Couplers Using Open Ended Stubs,” 1st International Conference on Computing, Electrical and Electronic Engineering (ICCEEE 2013)", Khartoum , Sudan 26 – 28 August 2013.
- [10] K.-O. Sun, S.-J. Ho, C.-C. Yen, and D. Weide, (2005) “A compact Branch-line Coupler Using Discontinuous Microstrip lines”, *IEEE Microwave Wireless Compon. Lett.* 15, 519–520.
- [11] Leung Chiu, (2014) “Wideband Microstrip 90° Hybrid Coupler Using High Pass Network,” *International Journal of Microwave Science and Technology*, vol. 2014, Article ID 854346, 6 pages, 2014. doi:10.1155/2014/854346.
- [12] S. N. D. Azizi, S.K.A.Rahim, M.I.Sabran, (2011) “Realization of a Compact Branch Line Coupler Using Semi-Lumped Element,” in *IEEE Symposium on Wireless Technology and Applications (ISWTA)*, Sep.2011.
- [13] CST Microwave Studio Ver. 2012.