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# An Ultra Compact Microstrip Branch Line Coupler with Wide Stopband Using LCL Filter and Meandered Stubs for Microwave Applications

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**Abstract:** A branch line coupler (BLC) with ultra-compact size and harmonic suppression ability using an LCL filter and meandered stubs is proposed in this paper. There are some important factors in microstrip coupler design, including size reduction, harmonic suppression, and low insertion loss. Thus, improving each of these factors will contribute to a more efficient design. In the proposed circuit, for the first time, LCL filters, including four T-shaped circuits and four meandered line open-ended stubs, were used together to reduce the circuit size and suppress unwanted harmonics. The proposed LCL filters, incorporated in the BLC branches, resulted in superior size reduction and harmonic suppression for the presented BLC. The proposed BLC correctly worked at 900 MHz with 300 MHz operating bandwidth, which showed 33% fractional bandwidth (FBW). Additionally, a wide suppression band from 1.4 GHz to 8.8 GHz, with more than 20 dB attenuation level was obtained, which suppressed the second to ninth unwanted harmonics. The overall size of the proposed 900 MHz coupler was only 11 mm × 10.4 mm (0.044 λ × 0.042 λ) while the size of the conventional 900 MHz coupler was 61.5 mm × 62.5 mm (0.25 λ × 25 λ). The proposed BLC had a very small size and only occupied 3% of the size of the conventional coupler, which corresponded to a 97% size reduction. To the best of the authors' knowledge, to date, the best size reduction has been obtained among the published couplers. Furthermore, the experimental results verified the simulated and analyzed results of the proposed technique and demonstrate its potential for improving the performance and miniaturizing the size of other similar BLCs.

**Keywords:** microstrip coupler; harmonic suppression; lumped component; communication systems



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## 1. Introduction

The microstrip branch line coupler (BLC) is a widely used microwave component that can divide or combine the power of a signal with a phase difference of 90 degrees. A BLC is a passive microwave device that splits or combines electromagnetic signals in a balanced manner. The typical BLC includes four transmission lines arranged in a rectangular configuration to achieve signal splitting or combining. The main purpose of a BLC is to provide power division and isolation between its ports. In microwave applications, BLCs are commonly used in communication systems, such as cellular networks and radar systems. BLCs play a key role in communication devices and systems, especially in LTE (long-term evolution) systems. LTE systems rely on efficient signal distribution and management to provide high-speed data transfer and reliable communication. BLCs can split the signal, allowing a single input signal to be divided into multiple output signals. This capability is particularly useful in LTE base stations, where the signal can be efficiently distributed to multiple antennas, thereby enhancing coverage and capacity. In addition, BLCs enable signal combining, allowing multiple signals to be merged into a single output.

This ability is valuable in scenarios such as combining signals from multiple small cells or antennas to strengthen the overall transmission power. In addition, BLC devices facilitate signal isolation, minimizing signal interference and maintaining the integrity of transmitted data. Their isolation ability ensures that transmitted signals from one antenna will not affect neighboring antennas, preventing signal degradation and enhancing overall network performance. Therefore, the utilization of BLCs in communication systems, particularly in LTE systems, plays a key role in improving system performance [1–3].

However, a drawback of conventional BLCs is that they pass unwanted harmonics along with desired signals without any attenuation. Therefore, there has been increasing interest in designing compact branch line couplers with harmonic suppression for various applications, such as communication systems and radar. In addition, in conventional BLCs, the length of the four lines is $\lambda/4$ at the center band, which makes the size inconvenient at the design frequency.

In recent years, several studies have examined how to achieve compact BLCs with harmonic suppression using different methods. One approach is to use different shape resonators to achieve a BLC with high performance. For example, in [4], low pass resonators and meandered lines were incorporated to design the BLC, which achieved a wide suppression band. In [5], split ring resonators were used to design a BLC with wide operating bands. Multi-stage resonators were used in [5] to obtain higher bandwidth. Moreover, stepped impedance resonators have been used in several approaches, such as in [2,6,7], to design couplers with high performance. Short-circuited stubs, open-circuited stubs, and stepped-impedance resonators were used in [7] to propose a compact branch line coupler with harmonic suppression and compact size.

Coupled lines can also be used to suppress harmonics in BLCs [8–13]. For example, in [8], a compact BLC with harmonic rejection using T-shaped coupled lines was presented. This presented coupler reduced the overall size to about 55%, compared with the conventional designs, and also provided good performance at operating frequencies with more than 20 dB return loss. Coupled lines and meandered lines were incorporated in [9] to obtain a compact BLC, which occupied 28% of the size of the conventional coupler. In addition, meandered lines and discontinuous lines were used to design a BLC in [13] to achieve a device of a reduced size. An overall 60% size reduction and high isolation were achieved in [13] using this technique. In [14], a BLC with coupled lines and open-circuited lines was designed, which achieved a 49% fractional bandwidth. The utilized coupled lines provided a suppression band, which could suppress up to the second harmonic for this device. Coupled lines were used in [15] to design a dual-band BLC with wideband operation. Furthermore, in this BLC, the coupled lines were used as impedance transformers with dual-band operation.

In [16–19], the defected ground structure (DGS) technique was used to design compact branch line couplers with harmonic suppression. In [16], rectangular-shaped DGSs were incorporated to design a BLC that achieved more than 30 dB attenuation for third harmonic. In addition, in [17], strip lines DGSs were used in the structure of the BLC, which archived a 33% size reduction compared with the typical coupler. Moreover, electromagnetic band-gap (EBG) structures are cells that can block electromagnetic waves in certain frequency ranges. They are commonly used in microwave couplers and power dividers to improve their performance. In these devices [20–23], EBG cells are placed between the input and output ports to suppress unwanted harmonics and improve isolation between the ports. The advantages of using EBG structures in microwave couplers and power dividers include performance improvement, bandwidth increment, and size reduction. EBG structures can also be used for mutual coupling reduction in antenna applications [24,25]. However, there are also some drawbacks to using EBG structures. The fabrication process for these structures can be complex and expensive, which can increase the overall cost of the device. Additionally, the performance of EBG structures can be affected by changes in temperature and humidity. Several studies have investigated the use of EBG cells for harmonics suppression in microwave circuits, and have shown that this technique can be effective over a wide frequency range. However, the complex fabrication process would be a drawback.

Open-ended and short-ended stubs are common techniques, which can be used for providing suppression bands and can reduce the device size simultaneously [26–29]. In [26], a compact BLC with harmonic suppression using open-ended stubs and hairpin-shaped resonators is reported, which achieved about a 64% size reduction. T-shaped resonators and open stubs were incorporated in [27] to design a BLC with more than 30 dB insertion loss and high isolation. Crossed lines and open stubs were used in the structure of the BLC in [28], which resulted in dual-band operation and different power split ratios.

Moreover, in the design of BLC and power splitter devices, photonic crystals [30–32] can be applied for operations at higher frequencies, which can result in performance improvement [33–36]. Recently, neural network and artificial intelligence techniques [37–40] have been reported for the performance improvement of electronic circuits and devices [7,41,42], which have also been incorporated into the designs of filters and couplers [7,43].

Non-uniform transmission lines are other structures that are used in microwave couplers and power dividers to improve performance and suppress harmonics [44–47]. Non-uniform transmission lines have an irregular structure, where the width and spacing of the conductors vary along the length of the line. This variation in the structure of the line causes a change in the characteristic impedance, which results in the distribution of microwave signals. One advantage of using non-uniform transmission lines in microwave couplers and power dividers is that they can provide a wide range of coupling values and reduce circuit size. Another advantage is that they can be designed to operate over a wide frequency range, making them useful in a variety of applications. However, there are also some drawbacks to using non-uniform transmission lines; one of the main drawbacks is that they can be difficult to design and fabricate, particularly for high-frequency applications. Additionally, the non-uniform structure of the line can cause signal distortion and loss, which can limit their performance in certain applications. Several studies have explored the use of non-uniform transmission lines for harmonics suppression and size reduction [44–47]. In these works, applied non-uniform transmission lines have an irregular structure which makes analysis difficult, and also the insertion loss values are high, which limits performance.

In all the mentioned literature, the explained works have partially succeeded to improve the performance of the BLC device in terms of size reduction and harmonic suppression, but no studies have achieved the perfect high improvement of both parameters. In addition, the applied techniques used in research studies have some limitations and disadvantages. For instance, using open stubs only can provide a single transmission zero, and creating a wide stop band needs several open stubs. Meanwhile, providing transmission zeros in desired frequency may be needed to create an over-length open stub. Using DGS and EBG structures adds extra steps to the implementation process and makes the design complicated for fabrication. Using coupled lines in the structure creates a limitation in design because of small gaps and the sensitivity of the structure to these gaps. However, in this paper, a new method is presented, which utilizes a capacitor and two inductors in a T-shaped structure with two transmission lines to create composite lines. These composite lines and four bended open-ended stubs were used together to design the proposed branch line coupler, which resulted in the improvement of coupler performance in terms of extreme miniaturization and harmonic suppression along with the wide suppression band. Therefore, the designed compact branch line coupler with the achieved wide suppression band resulted in overall linearity improvement of the LTE systems.

## 2. Design Process of the Proposed Branch Line Coupler

In this section, as the first step, the conventional BLC and its disadvantages are explained. Then, the preliminary BLC is presented, which used the new proposed branches to improve the conventional BLC functionality. As the next step, the proposed branch incorporated with the LCL filter was analyzed to calculate the dimensions of the proposed structure. Finally, the meandered lines were added in the preliminary BLC to solve its problems and form the proposed BLC.

*2.1. Design Process of the Conventional 900 MHz Branch Line Coupler*

The conventional 900 MHz branch line coupler includes four long λ/4 branches, corresponding to two 50 Ω vertical branches and two 35 Ω horizontal lines. With the applied 5880 RT-Duroid substrate, the typical BLC size is obtained and is equal to 61.5 mm × 62.5 mm. This large size for the typical BLC is one of its drawbacks.

The S-parameters and structure of the conventional 900 MHz branch line coupler are depicted in Figure 1. The amplitudes of $S_{21}$ and $S_{31}$ are −3.1 dB, indicating a 0.1 dB insertion loss at the operating frequency. The amplitudes of $S_{11}$ and $S_{41}$ are less than −30 dB, which demonstrates that the conventional coupler has good performance at the operating frequency. However, it is important to note that while the conventional BLC performs well at the operating frequency, it does not perform well at higher frequencies. This means that unwanted signals can pass without any suppression at higher frequencies, which is another drawback of this typical coupler.

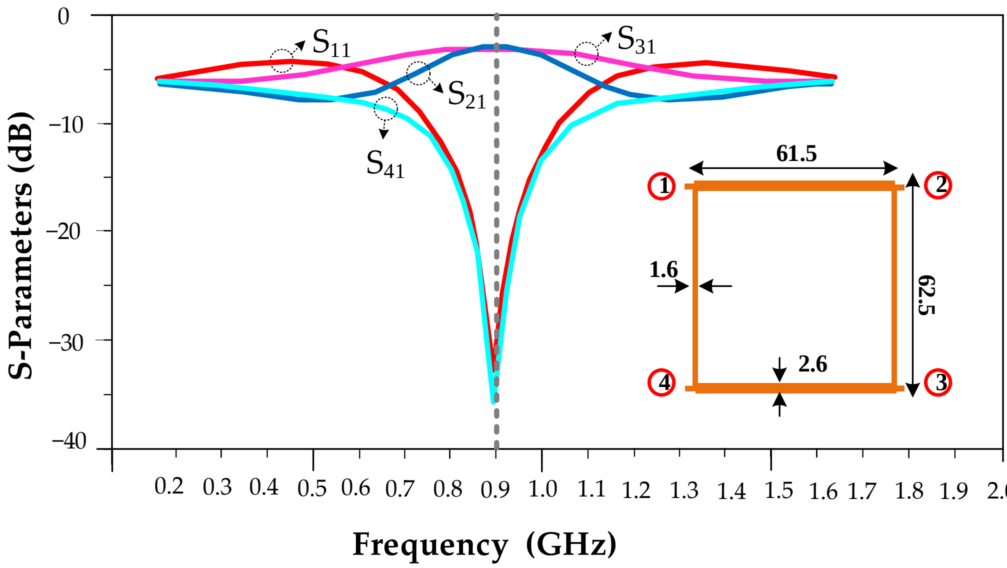


**Figure 1.** The S-parameters and structure of the conventional 900 MHz branch line coupler.

*2.2. Design Process of the Preliminary 900 MHz Branch Line Coupler*

As mentioned earlier, the conventional BLC is large in size and allows undesirable signals to pass through at higher frequencies without any suppression. This is not desirable; therefore, to overcome these disadvantages, a preliminary structure is proposed in Figure 2, in which two lumped inductors and a capacitor are used instead of the long branch of the typical BLC.

The preliminary 900 MHz branch line coupler used two types of composite lines that contained lumped L and C components, rather than long conventional λ/4 branches. The conventional horizontal branches consisted of two 90-degree length lines with 35.5 ohms impedance (2.6 mm width). However, the preliminary coupler implemented a new horizontal composite branch, as shown in Figure 2. The S-parameters of the typical horizontal λ/4 line and the presented compact horizontal line are compared in Figure 3, revealing that both lines exhibited the same insertion loss of 0.1 dB at the 900 MHz main frequency. Moreover, the presented horizontal transmission line exhibited a wide suppression band that began at 3.3 GHz, with a suppression level exceeding 20 dB, while the conventional line cannot reject any harmonic. The analyses of the proposed compact horizontal and vertical lines are explained in Section 2.3.

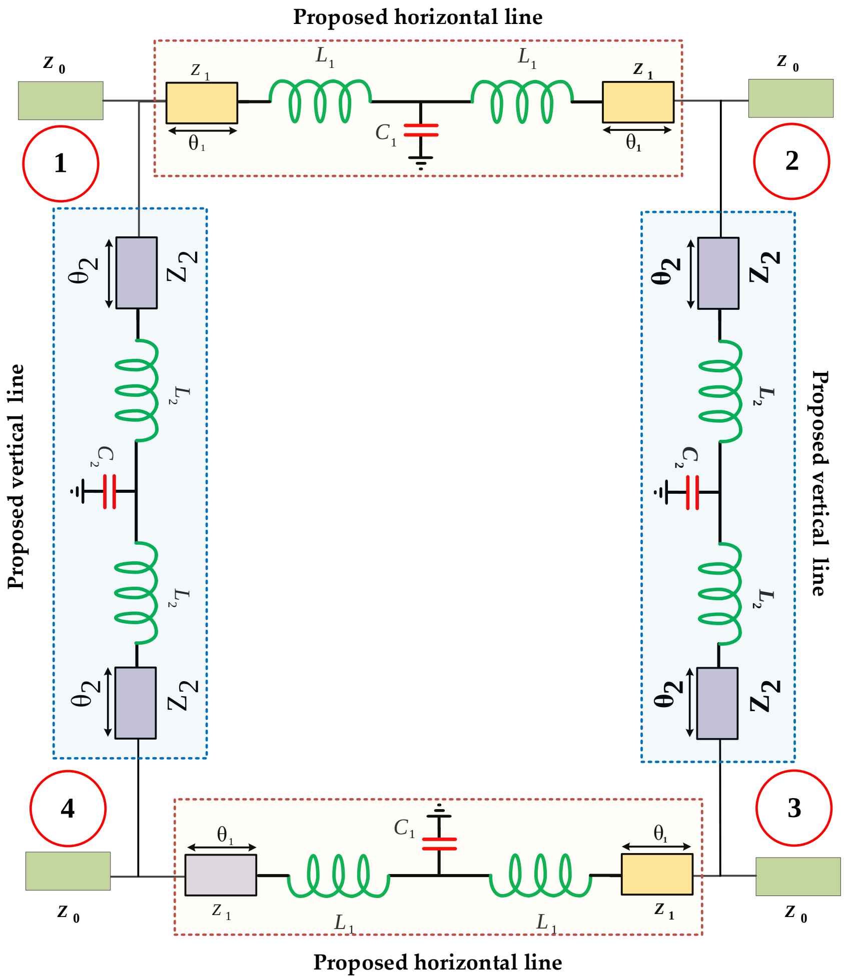


**Figure 2.** The schematic diagram of the preliminary 900 MHz branch line coupler using LCL filters.

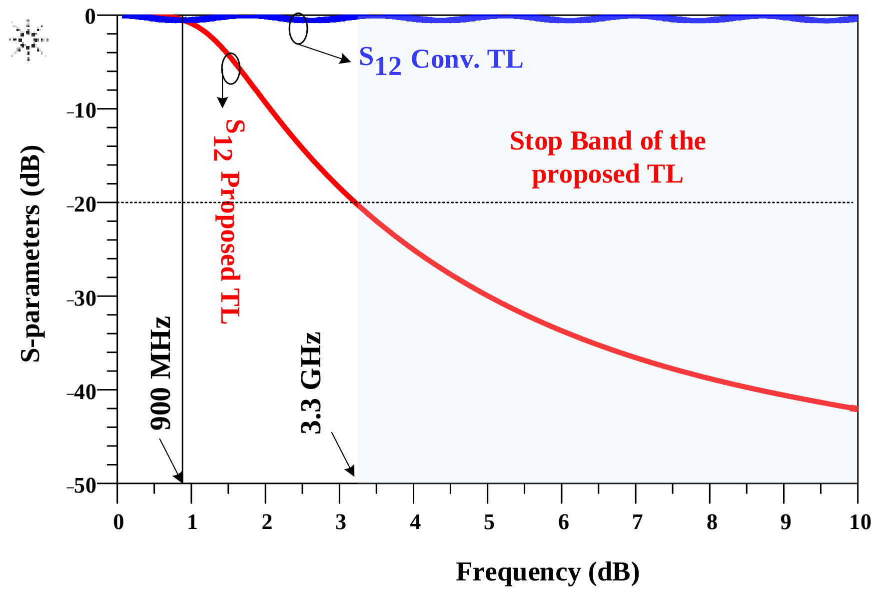


**Figure 3.** The S-parameters of the typical 90-degree line and proposed horizontal 90-degree line with LCL filter for the BLC.

*2.3. Analyses of the Proposed LCL Filter Branch*

To analyze the proposed LCL filter branch at the first step, the ABCD matrix of the LCL branch should be extracted, which is defined in Equation (1):

$$\mathrm{ABCD_{LCL}} = \begin{pmatrix} 1 - C\,L\,w^2 & L\,w\,\mathrm{i} - L\,w\,\left(C\,L\,w^2 - 1\right)\mathrm{i} \\ C\,w\,\mathrm{i} & 1 - C\,L\,w^2 \end{pmatrix} \quad (1)$$

Furthermore, the ABCD matrix of the transmission line with impedance of $Z_1$ and electrical length of $\theta_1$ can be defined as written in Equation (2):

$$\mathrm{ABCD_{TL}} = \begin{pmatrix} \cos(\theta_1) & Z_1\,\sin(\theta_1)\,\mathrm{i} \\ \frac{\sin(\theta_1)\,\mathrm{i}}{Z_1} & \cos(\theta_1) \end{pmatrix} \quad (2)$$

Finally, by using Equation (3), the total ABCD matrix of the designed horizontal and vertical branches, incorporated with the proposed LCL filter, can be extracted as written in Equation (4), where the parameters are defined as in Equations (5)–(9). Equation (3) shows that the total ABCD matrix of the designed branch, incorporated with the proposed LCL filter ($\mathrm{ABCD_{BR}}$) can be obtained through the multiplication of the transmission line matrix ($\mathrm{ABCD_{TL}}$) and the proposed LCL filter matrix ($\mathrm{ABCD_{LCL}}$), as shown in the equation.

$$[ABCD_{BR}]_{2\times2} = [ABCD_{TL}]_{2\times2} \times [ABCD_{LCL}]_{2\times2} \times [ABCD_{TL}]_{2\times2} \quad (3)$$

$$\begin{pmatrix} -\cos(\theta_1)\sigma_4 + \frac{\sin(\theta_1)\sigma_2\mathrm{i}}{Z_1} & \cos(\theta_1)\sigma_2 - Z_1\sin(\theta_1)\sigma_4\mathrm{i} \\ -\cos(\theta_1)\sigma_3 - \frac{\sin(\theta_1)\sigma_1\mathrm{i}}{Z_1} & -\cos(\theta_1)\sigma_1 - Z_1\sin(\theta_1)\sigma_3\mathrm{i} \end{pmatrix} \quad (4)$$

$$\sigma_1 = \cos(\theta_1)\sigma_5 - \frac{\sin(\theta_1)(Lw\mathrm{i} - Lw\sigma_5\mathrm{i})\mathrm{i}}{Z_1} \quad (5)$$

$$\sigma_2 = \cos(\theta_1)(Lw\mathrm{i} - Lw\sigma_5\mathrm{i}) - Z_1\sin(\theta_1)\sigma_5\mathrm{i} \quad (6)$$

$$\sigma_3 = \frac{\sin(\theta_1)\,\sigma_5\,\mathrm{i}}{Z_1} - C\,w\,\cos(\theta_1)\,\mathrm{i} \quad (7)$$

$$\sigma_4 = \cos(\theta_1)\sigma_5 + CZ_1w\sin(\theta_1) \quad (8)$$

$$\sigma_5 = CLw^2 - 1 \quad (9)$$

By equating the total ABCD matrix of the designed branch with the ABCD matrix of the typical λ/4 branch, the unknown parameters of the proposed branch can be obtained. Some assumptions should be considered for solving the equations; for instance, considering the desired values of $Z_1$ and $\theta_1$ for the desired size reduction value. The values of applied components in the proposed horizontal line are then calculated, which are listed as follows: $C_1$ = 4.7 pF, $L_1$ = 4.7 nH, $Z_1$ = 70 Ω (0.9 mm), $\theta_1$= 5.5° (3.8 mm).

Moreover, in the conventional BLC, two vertical 90-degree branches with 50 ohms impedance (1.6 mm width) are used. In the preliminary coupler, the proposed vertical composite branches were applied, as depicted in Figure 2.

Figure 4 illustrates a comparison of the S-parameters for the typical vertical λ/4 line and the presented compact vertical line, revealing that both lines have an insertion loss of 0.1 dB at the main frequency of 900 MHz. However, the presented vertical transmission line provides a broader suppression band that begins at 2.9 GHz and offers a suppression level greater than 20 dB. In contrast, the typical line cannot provide any suppression of harmonics.

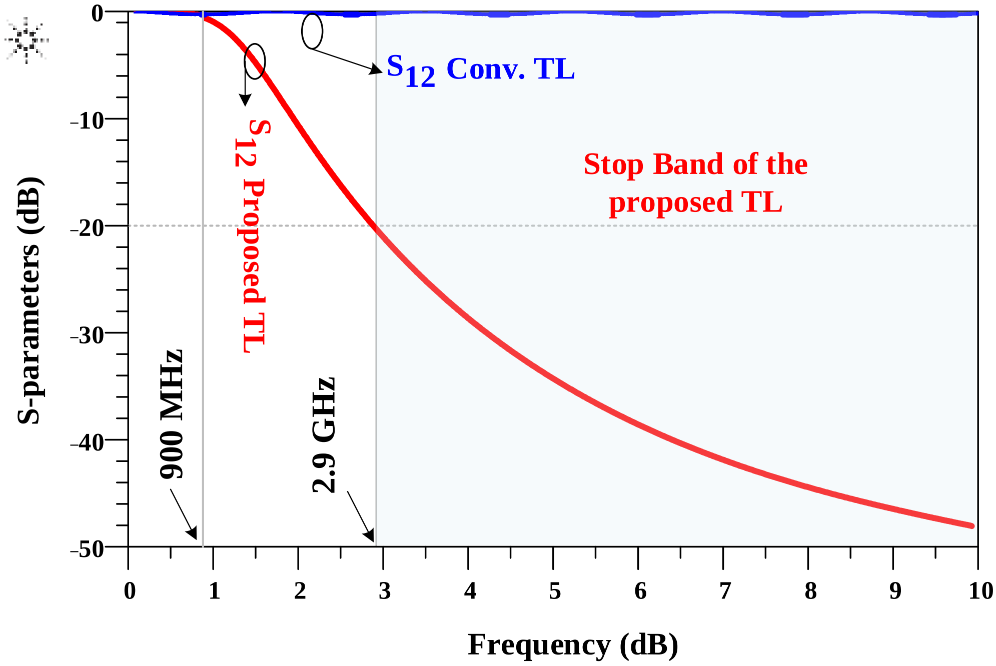


**Figure 4.** The S-parameters of the typical 90-degree line and proposed vertical 90-degree line with LCL filter for the BLC.

The value of applied components in the proposed vertical line can be calculated using the extracted analysis, which is listed as follows: $C_2$ = 3.3 pF, $L_2$ = 6.8 nH, $Z_1$ = 118 Ω (0.3 mm), $\theta_1$ = 6° (4.1 mm).

The obtained values of the lumped components and two side transmission lines for the proposed horizontal and vertical lines are listed in Table 1.

**Table 1.** The obtained values of the proposed horizontal and vertical branches.

| $L_1$ | $C_1$ | $Z_1$ | $\theta_1$ | $L_2$ | $C_2$ | $Z_2$ | $\theta_2$ |
|---|---|---|---|---|---|---|---|
| 4.7 nH | 4.7 pF | 70 Ω (0.9 mm) | 5.5° (3.8 mm) | 6.8 nH | 3.3 pF | 118 Ω (0.3 mm) | 6° (4.1 mm) |

The structure of the preliminary BLC, which provided an ultra-compact size, is depicted in Figure 5. The overall final size of the preliminary coupler was only 11 mm × 10.4 mm, which was equal to 0.044 λ × 0.042 λ and showed a 97% size reduction compared to the conventional 900 MHz coupler.

The S-parameters of the preliminary 900 MHz branch line coupler with lumped components are depicted in Figure 6. The operating bandwidth of the preliminary BLC was 200 MHz, which showed 22% FBW. The preliminary coupler had acceptable performance at 900 MHz, and provided a wide stop band from 3.2 GHz with more than a 20 dB attenuation level, which suppressed unwanted harmonics of the third order and higher harmonics. This structure had perfect performance in terms of size reduction, but regarding harmonics suppression ability, the second harmonic was not rejected.

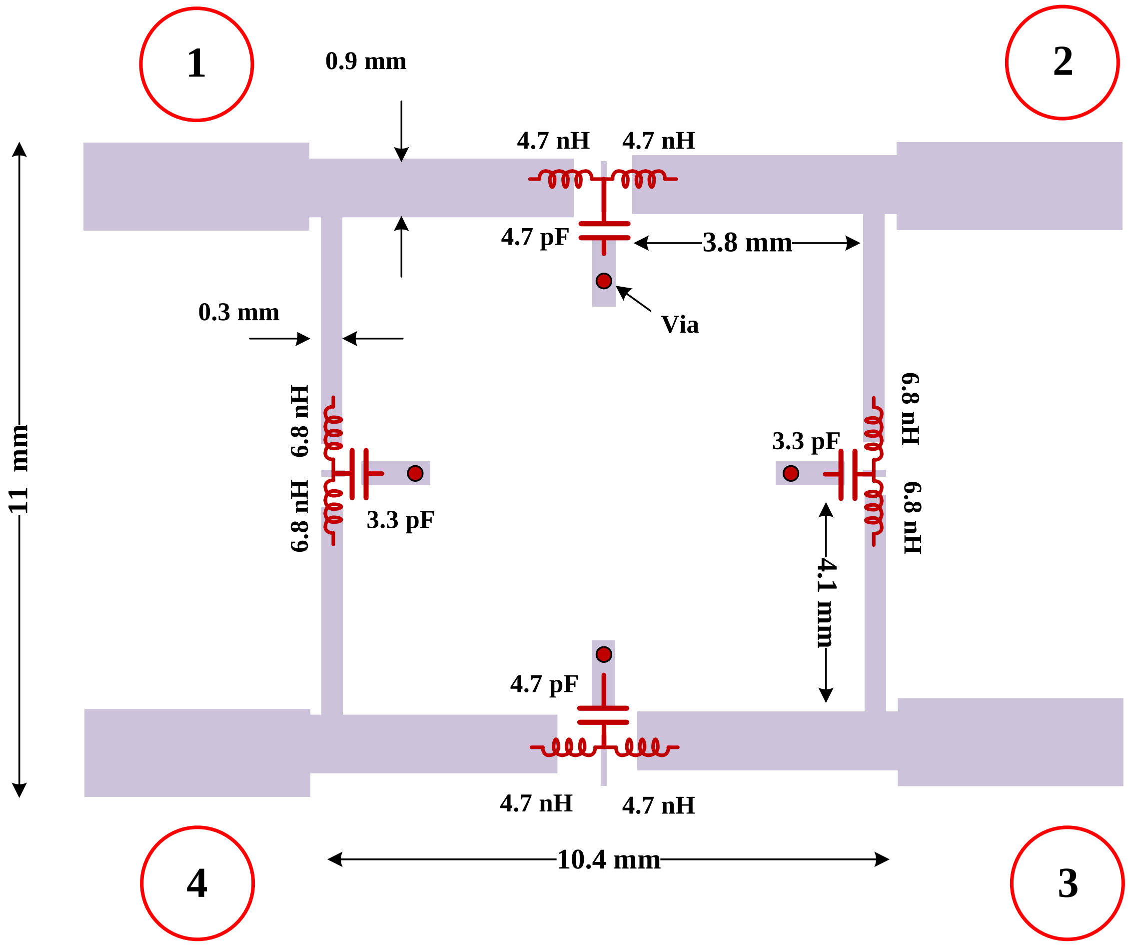


**Figure 5.** The structure of the preliminary 900 MHz branch line coupler with lumped components.

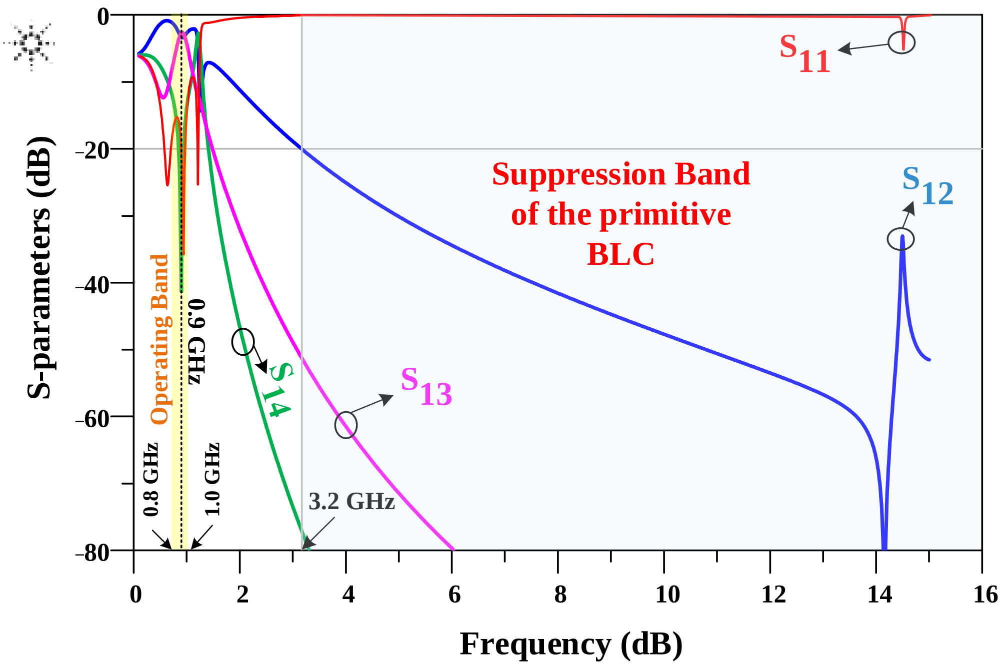


**Figure 6.** The S-parameters of the preliminary 900 MHz branch line coupler with lumped components.

### 2.4. Design Process of the Proposed 900 MHz Branch Line Coupler

As mentioned in the previous section, the preliminary 900 MHz branch line coupler did not suppress the second harmonic. In order to suppress the second harmonic, four open-ended stubs were used. Since the length of these open-ended stubs was too long, they were bended. In the proposed meandered lines, there were no significant coupling effects between transmission lines, because of its high impedance and rather large gap between the lines. But meandering the lines affected the overall response, such that the response of the meandered line was not equal to a straight line stub with the total length, the effect of which was considered in the EM simulation. The structure of the proposed 900 MHz branch line coupler with lumped components and four bended stubs is depicted in Figure 7. The overall occupied size of the proposed coupler, like the preliminary coupler, was only 11 mm × 10.4 mm, which was equal to 0.044 λ × 0.042 λ and showed a 97% size reduction compared to the conventional 900 MHz coupler.

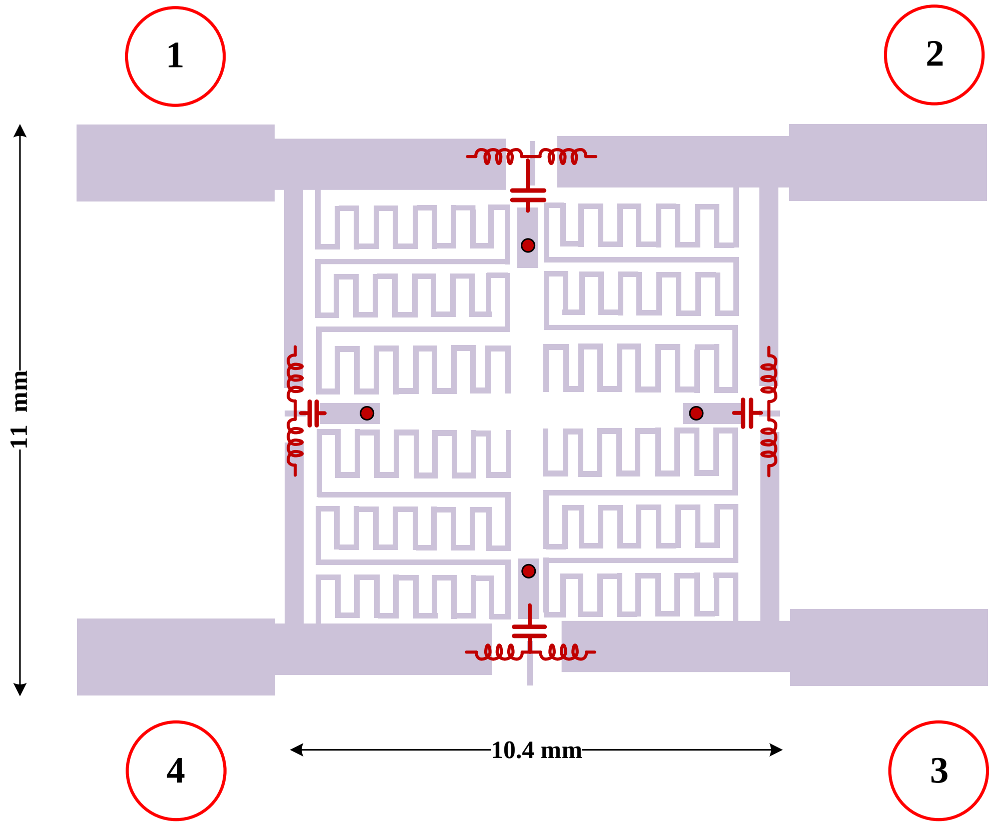


**Figure 7.** The structure of the proposed 900 MHz branch line coupler with lumped components and four bended stubs.

## 3. Results

The S-parameters of the proposed 900 MHz branch line coupler with lumped components and four bended stubs are depicted in Figure 8. The proposed coupler has perfect performance at 900 MHz and provided a wide stop band from 1.4 GHz to 8.8 GHz with more than 20 dB attenuation level, which suppressed the second to ninth unwanted harmonics. This structure had perfect performance in terms of size reduction and harmonics suppression. The operating bandwidth of the proposed BLC was 300 MHz, which shows 33% FBW.

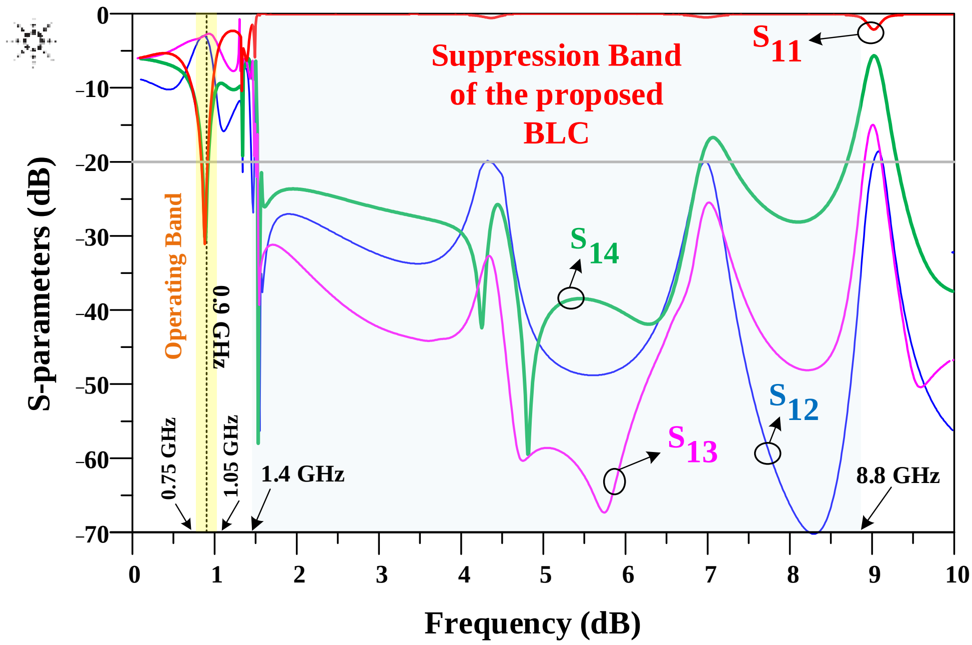


**Figure 8.** The S-parameters of the proposed 900 MHz branch line coupler with lumped components and bended stubs.

The sizes of the presented 900 MHz coupler and the conventional coupler are compared in Figure 9. As the results show, the size of the designed coupler was 97% smaller, compared with the conventional coupler. The overall size of the designed 900 MHz coupler was only 11 mm × 10.4 mm (0.044 λ × 0.042 λ) while the size of the conventional 900 MHz coupler is 61.5 mm × 62.5 mm (0.25 λ × 25 λ).

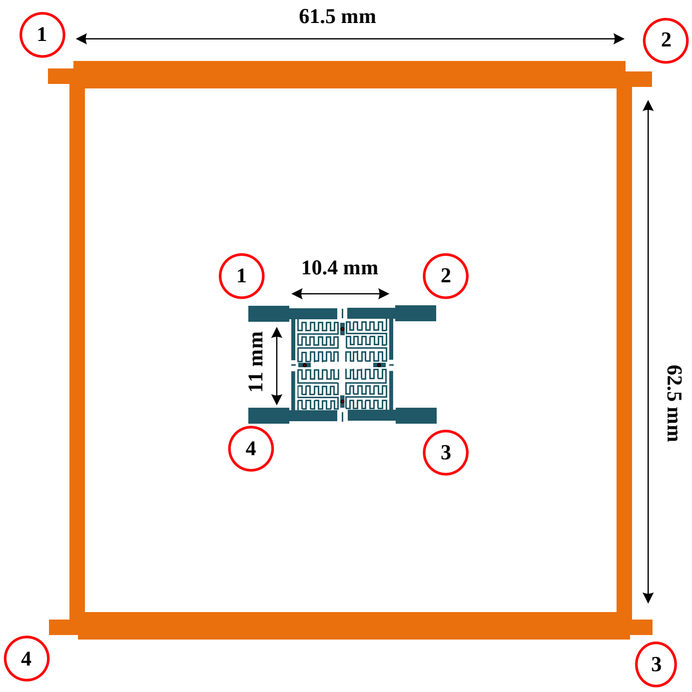


**Figure 9.** A size comparison of the proposed BLC and conventional 900 MHz BLC.

The fabricated prototype and test setup of the proposed 900 MHz BLC is depicted in Figure 10. As seen in the figure, at the first step, only microstrip lines were fabricated on the RT-Duroid 5880 substrate. With a 0.1 mm drill, four holes were then made to create four via holes in the board, which provided ground connections for the applied lumped capacitors. The top and back views of the completed connectorized device with soldered inductors and capacitors are also shown in Figure 10. Finally, the measured data were extracted, which validated the EM-simulated data.

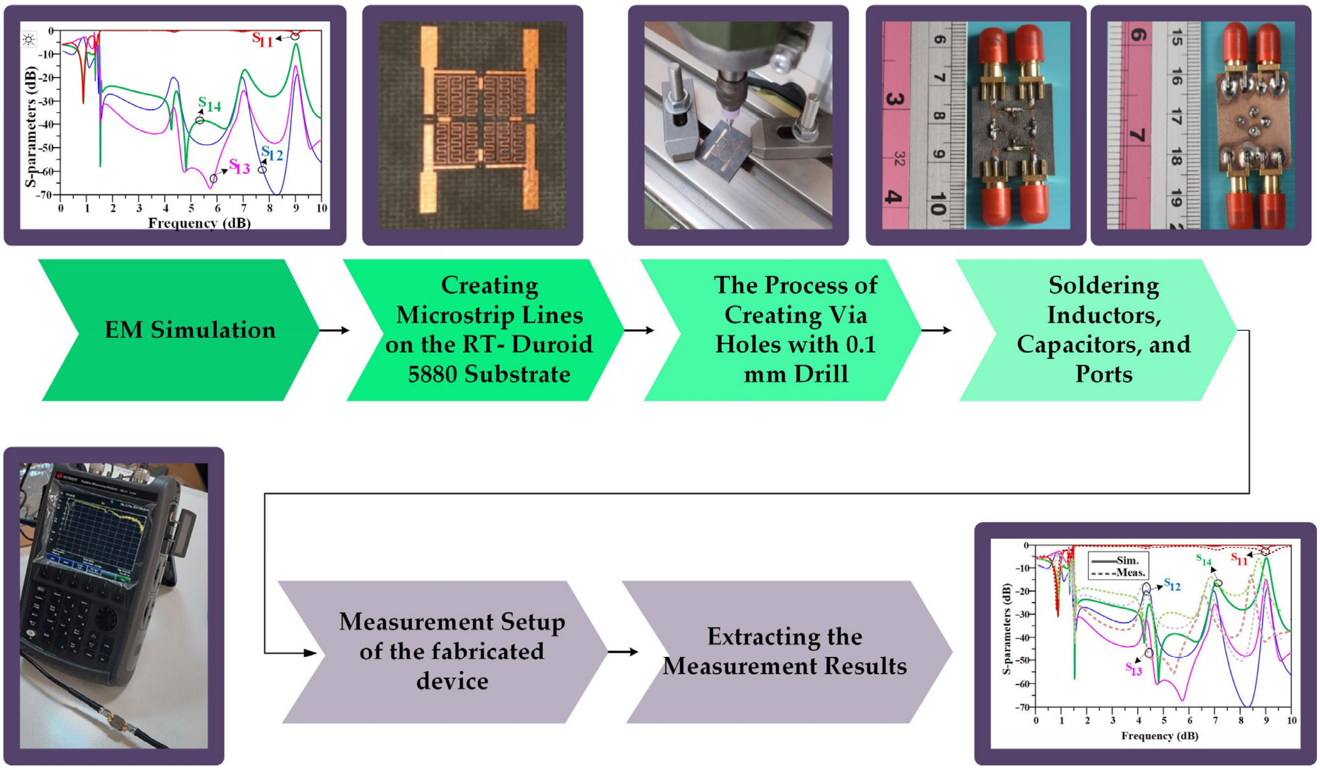


**Figure 10.** The fabricated prototype and test setup of the proposed 900 MHz BLC, including microstrip lines on the RT-Duroid 5880 substrate, the processes of creating via holes with 0.1 mm drill, soldering inductors and capacitors, and measuring the fabricated device.

The measured and simulated S-parameters of the designed 900 MHz branch line coupler, are depicted in Figure 11. The proposed coupler had a perfect performance at 900 MHz and provided a wide stop band from 1.4 GHz to 8.8 GHz with a more than 20 dB attenuation level, which suppressed the second to ninth unwanted harmonics. This structure has perfect performance in terms of size reduction and harmonics suppression. The operating bandwidth of the proposed BLC was about 300 MHz, which showed 33% FBW.

The measured and simulated phase difference of the output ports for the proposed 900 MHz BLC is depicted in Figure 12. As can be seen, the output ports phase difference of the designed coupler was equal to −270.8°, at an operating frequency of 900 MHz, which was extremely close to the ideal value.

The performance comparison between the proposed coupler and related works is listed in Table 2. The proposed coupler had the best size reduction compared with other reported works and provided a wide suppression band, which suppressed the second to ninth unwanted harmonics. Furthermore, the comparison showed the superior performance of the proposed BLC.

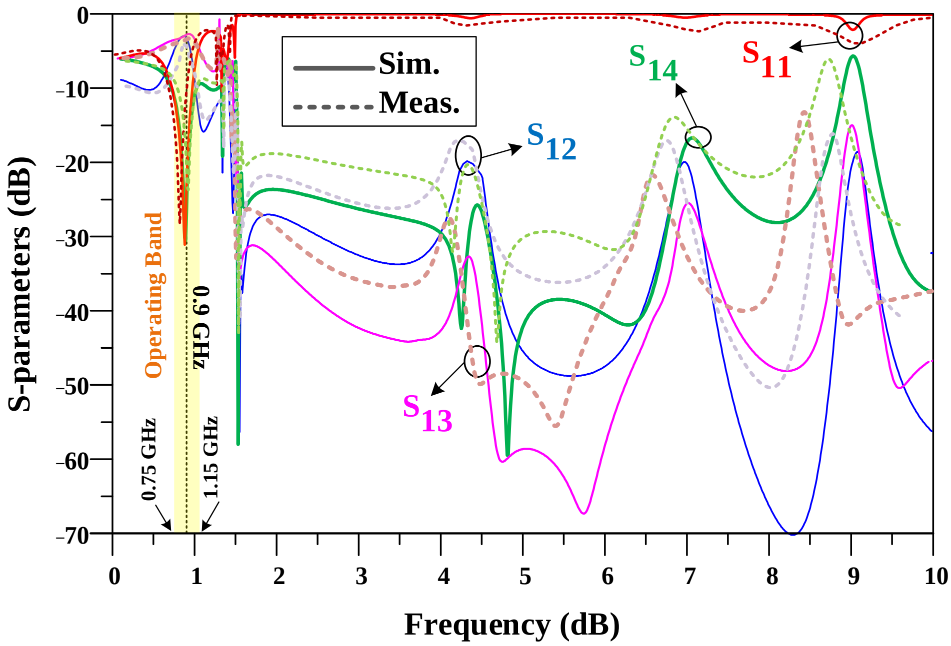


**Figure 11.** The measured and simulated results of the proposed 900 MHz BLC.

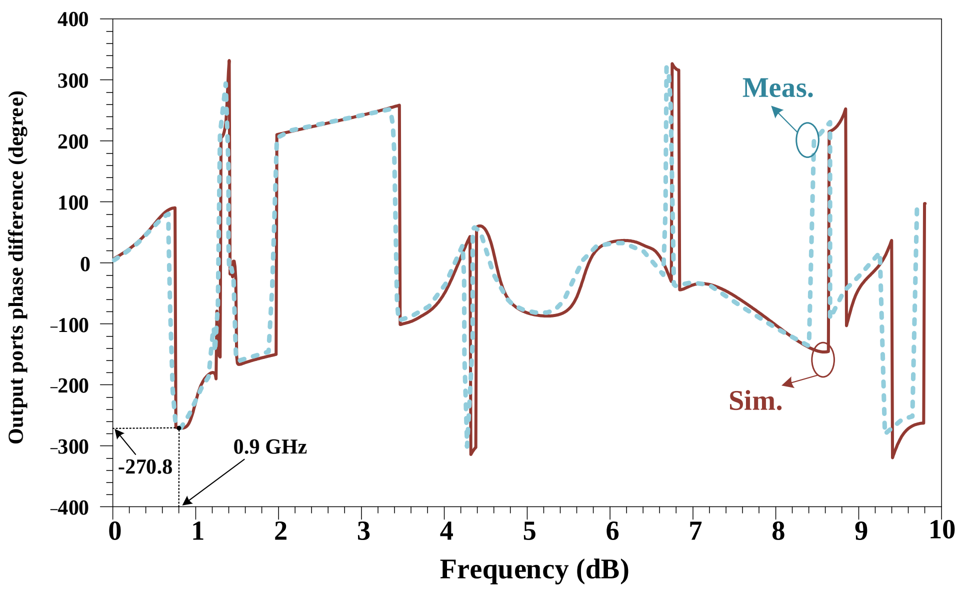


**Figure 12.** The measured and simulated phase difference of the output ports for the proposed 900 MHz BLC.

**Table 2.** A performance comparison between the presented 900 MHz BLC and related approaches.

| Ref | Device Type | Size Reduction | Harmonic Suppression | Applied Technique |
|---|---|---|---|---|
| [48] | RRC | 74% | 2nd–7th | Open Stubs |
| [49] | BLC | 39% | - | PBG and DGS |
| [50] | BLC | 40% | - | interdigital |
| [51] | BLC | 46% | - | divided lines |
| [52] | BLC | - | 2nd–4th | Non-uniform lines |
| [53] | BLC | 63% | 2nd, 3rd | Open stubs |
| [54] | BLC | 64% | 3rd, 5th | Resonators |
| This Work | BLC | 97% | 2nd–9th | LCL filter and meandered stubs |

## 4. Conclusions

In this paper, a compact BLC with harmonic suppression using lumped components and meandered stubs is proposed. In the proposed design, four T-shaped LC circuits and four transmission lines are used together, instead of the conventional branches. It was proposed that two vertical and horizontal 90-degree lines with LCL filters should be incorporated into the BLC structure. The proposed branches resulted in the performance improvement of the proposed BLC in terms of reducing its size and suppressing unwanted harmonics. The obtained harmonic suppression increased the overall efficiency of the system in the LTE and communications system applications. Moreover, the proposed LCL filter consists of capacitor and inductor lumped elements, and was designed to provide the filtering response and reduce the length of the lines while improving its functionality. The proposed BLC correctly worked at 900 MHz with 300 MHz bandwidth and showed 33% FBW. The proposed BLC has an ultra-small size and is only 3% of the size of the conventional coupler. The overall size of the proposed 900 MHz coupler is only 11 mm $\times$ 10.4 mm (0.044 $\lambda \times$ 0.042 $\lambda$) and the size of the conventional 900 MHz coupler is 61.5 mm$\times$ 62.5 mm (0.25 $\lambda \times$ 25 $\lambda$). In addition, the presented BLC provided a wide suppression band from 1.4 GHz to 8.8 GHz, which suppressed the second to ninth unwanted harmonics. The proposed BLC was fabricated and the measured results verified the simulated results.

**Author Contributions:** Conceptualization, S.R. (Saeed Roshani), S.R. (Sobhan Roshani) and M.A.C.; Formal analysis, S.R. (Saeed Roshani) and M.A.C.; Methodology, S.R. (Sobhan Roshani); Software, S.R. (Sobhan Roshani) and S.R. (Saeed Roshani); Validation, S.R. (Saeed Roshani), S.R. (Sobhan Roshani) and M.A.C.; Writing—original draft, S.R. (Saeed Roshani) and S.R. (Sobhan Roshani); Writing—review & editing, S.R. (Saeed Roshani) and M.A.C. All authors have read and agreed to the published version of the manuscript.

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