Miniaturized Wilkinson Power Divider with nth Harmonic Suppression using Front Coupled Tapered CMRC

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Abstract **─** In this paper, a novel microstrip power divider with a new technique for nth harmonic suppression is presented. This technique is based on using front coupled tapered compact microstrip resonant cell (FCTCMRC) that inserted into a quarter-wavelength transmission line of the conventional Wilkinson power divider. This cell is used to obtain high harmonic suppression. The proposed power divider not only impressively improves harmonic suppression, but also reduces the length of a quarter-wave line over 29.3 % as compared with the conventional power divider. From the measured results, the proposed structure achieved ultra wide stop-band bandwidth (6 GHz – 12 GHz) with a minimum attenuation level of 24 dB, while maintaining the characteristics of the conventional Wilkinson power divider. The input and output return losses at 2 GHz are 48 and 44 dB, respectively. The insertion loss is about 3.1 dB and better than 45 dB isolation is obtained.

Index Terms **-** Front coupled tapered compact microstrip resonant cell, harmonic suppression, miniaturization, and Wilkinson power divider.

I. INTRODUCTION

The power divider was first presented by J. Wilkinson in 1960 [1]. Power dividers are widely used in different microwave applications such as frequency multipliers, mixers, and power amplifiers [2]. The unwanted harmonics caused by nonlinear property of the active circuit should be removed. It will be cost-effective if the unwanted harmonics suppressed in the power divider or the combiner structure [3]. The conventional power divider consists of two quarter-wavelength transmission lines at the designed frequency that results in a large occupied area, especially at low frequencies. Thus, several methods have been proposed so far to design miniaturized harmonic suppressed power dividers with improved performance [3-7]. In [3] and [4] microstrip electromagnetic band-gap (EBG) structures have been applied to design power dividers. Thus, compact Wilkinson power dividers with harmonic suppression are realized due to the slow wave characteristics and band-stop of EBG. Power dividers with EBG cells have also reduced the occupied area. Furthermore, as defected ground structure (DGS) can provide the same properties as EBG, it has also been used to design compact power dividers with harmonic suppression. In [5] a miniaturized microstrip Wilkinson power divider based on standard PCB etching processes has been designed. It is composed of four microstrip high-low impedance resonator cells uniformly placed inside the Wilkinson power divider resulting in the high slow-wave effect. This power divider reduces the occupied area to 36.5 % of the conventional

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one at 2.65 GHz. In [5] the third and fifth harmonic suppression levels are about 29 and 34 dB, respectively. Another power divider for the nth harmonic suppression has been presented that consists of two quarter-wavelength open stubs, which are located at the center of the quarter-wavelength branch-lines [6]. However, the physical dimensions of a power divider are proportional to the wavelength of the center frequency. A Wilkinson power divider with an asymmetric spiral defected ground structure (DGS) in a quarter-wave line for harmonic suppression has been demonstrated in [7]. Unfortunately, the major drawback of all works that have been referred above is that all of them need etching or back side processing or lumped reactive components.

In [8] and [9] the non-uniform transmission lines (NTLs) method has been used to reduce the circuit area and to suppress the harmonics of the fundamental frequency. However, in these works, obtaining harmonic suppression with high level of attenuation is still subject of discussion and challenge.

In this paper, the proposed power divider has very simple topology that only uses microstrip line and reduces the length of a quarter-wave line over 29.3 % as compared to the conventional divider at 2 GHz. Furthermore, it has an ultra wide stop-band bandwidth (6 GHz – 12 GHz) with a minimum attenuation level of 24 dB. This power divider suppresses the unwanted harmonics better than previous works without the need of backside etching or lumped reactive components.

II. CIRCUIT DESIGN

Figure 1 (a) shows the conventional Wilkinson power divider that consists of two quarter-wavelength transmission lines ($\sqrt{2}\ Z_0$) and an isolation resistor (100 ohms). Figure 1(b) shows the schematic diagram of the proposed power divider, which consists of two FCTCMRC [10] that are placed within a quarter-wavelength transmission line of the conventional Wilkinson power divider. The aim of the inserted cells is to improve the performance of the power divider. The FCTCMRC acts as a low pass resonator that suppresses the unwanted harmonics.

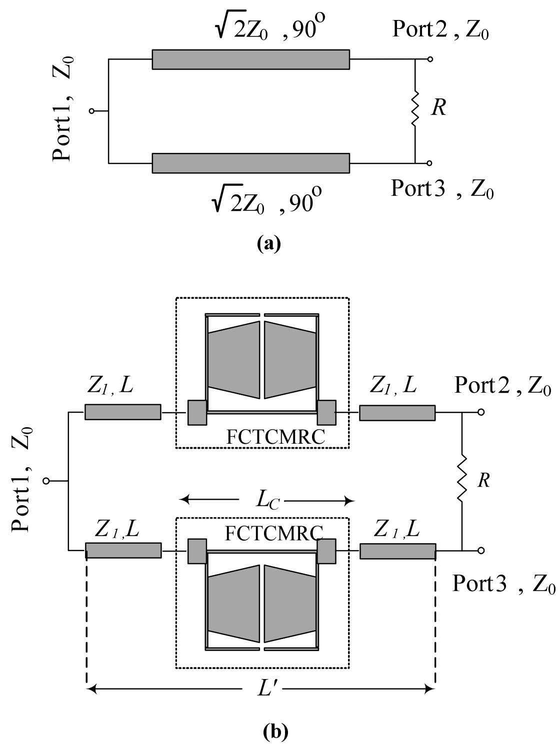


Fig. 1. Schematic diagram of the (a) conventional Wilkinson power divider and (b) proposed power divider using FCTCMRC.

Figure 2 demonstrates the FCTCMRC, which consists of two tapered cells, connected to the high impedance segment. They are essential blocks for harmonic suppression and stop-band improvement, because of their high capacitance and inductance properties.

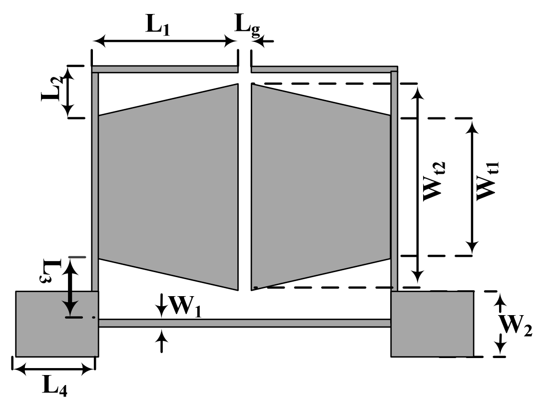
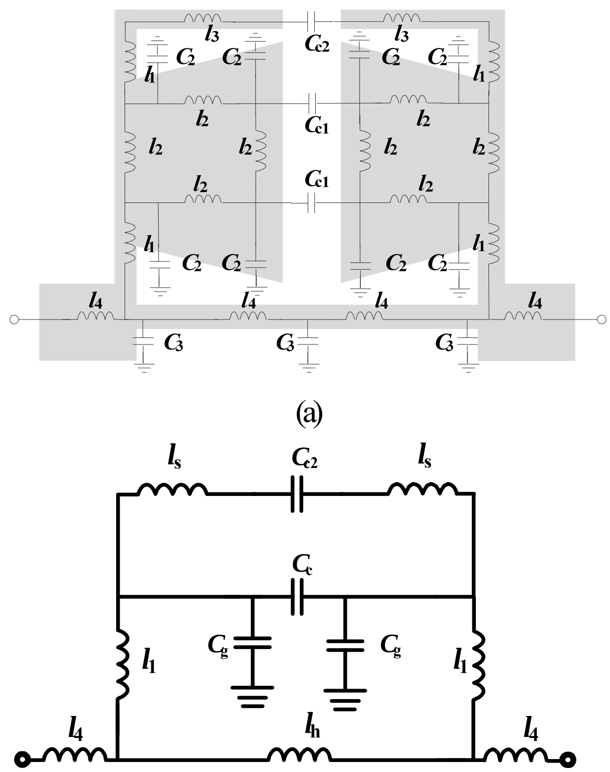


Fig. 2. Structure of the front coupled tapered CMRC.

The dimensions of FCTCMRC are obtained as follows: L_1 = 2.2 mm, L_2 = 0.75 mm, L_3 = 1.1 mm, L_4 = 1.1 mm, Lg = 0.2 mm, W_1 = 0.1 mm, W_2 = 1 mm, W_{t1} = 2.1 mm, and W_{t2} = 3.1 mm. The LC equivalent circuit of the FCTCMRC is introduced to understand the effect of variations in the dimensions of the proposed cell on inductances and capacitances and thereby to know their effect on the transmission zeros, and finally on the frequency response of the cell. In [11], the LC equivalent circuits for microstrip steps, open-ends, bends, gaps, and junctions are presented. Based on it, the LC equivalent circuit of the FCTCMRC is achieved. The relation between the reactive elements and geometrical parts of the microstrip cell such as transmission lines and gaps is shown in Fig. 3(a); where, l_4 is the inductance of feeding lines, C_3 is the capacitance between feeding and matching lines with respect to the ground, and the inductance of the high impedance lines is l_1, where the tapered cells are attached. In addition l_2 and C_2 are the inductance and the capacitance with respect to the ground of the tapered cell, respectively. The l_3 represents the inductance of the high impedance lines with length of L_1. Also C_{c2} is the coupling capacitance between two high impedance lines with length of L_1, and C_{C1} is the coupling capacitance between the tapered cells.

Figure 3 (b) depicts the simplified LC equivalent circuit of Fig. 3 (a). In this figure, l_2 is neglected due to the low impedance of tapered cell. Therefore, by eliminating l_2, the capacitor of C_g and C_C will be equal to $4C_2$ and $2C_{C1}$ respectively; furthermore, l_s will be l_3 + l_1 and finally, the equivalent circuit of the lower high impedance transmission line, is simplified to l_h. The component values of the simplified LC equivalent circuit is obtained, where l_h = 4 nH, l_1 = 2nH, l_s=2 nH, l_4=0.2nH, C_{c2} = 1pF, C_c = 19 pF and C_g=175pF. Figure 4 shows the electromagnetic (EM) and simplified LC equivalent circuit simulation results of the optimized FCTCMRC for harmonic suppression. As seen in this figure, the FCTCMRC has two transmission notches near 6 GHz and 10 GHz (3^{rd} and 5^{th} harmonics) with the rejection level of 51 dB and 49 dB, respectively, and it has better than 18 dB rejection level in the whole 6 GHz-12 GHz band. These results show the implementation feasibility of the power divider with high suppression of harmonics using FCTCMRC.



(a)

(b)

Fig. 3. (a) The derivation of LC equivalent circuit from FCTCMRC and (b) the simplified LC equivalent circuit of the FCTCMRC.

As seen in Fig. 4, there is a good agreement between the simplified LC equivalent circuit response and the EM simulation results. The EM simulated magnitude and phase responses of S_{12} of the FCTCMRC as the functions of L_1 are shown in Figs. 5 and 6. By adjusting the length of L_1, the desired performance can be achieved. It is also possible for the proposed structure to move the transmission notches close enough to the 2^{nd} and 3^{rd} harmonics by adjusting the length of L_1. With L_1= 5.5 mm the second and third harmonics are suppressed, as shown in Fig. 5.

Figure 7 shows the simulated responses of S_{12} for the simplified LC equivalent circuit as the function of C_g. The location of the transmission notches changes, by adjusting the value of C_g. The configuration of the proposed power divider for nth harmonic suppression as shown in Fig. 1 (b) consists of two microstrip FCTCMRC and four microstrip branch lines. Furthermore, the output ports are shunted through 100 ohms resistor. The impedance of the microstrip branch lines connected to the input and output ports is represented by Z_1, and its length is represented by L. In the proposed power divider, the overall length of the quarter-wavelength transmission line is calculated as,

$$L' = (2 \times L) + L_C \quad (1)$$

where L_C is the length of the FCTCMRC that is equal to $2 \times (L_1 + L_4) + Lg = 6.8$ mm. Due to the slow-wave effect of the FCTCMRC, the dimension of L' = 17.86 mm, which is 29.3 % smaller than the conventional quarter-wavelength (25.28 mm).

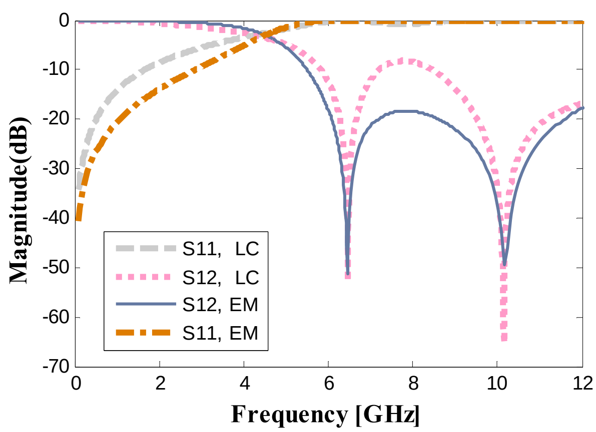


Fig. 4. EM and simplified LC equivalent circuit simulation results for the FCTCMRC.

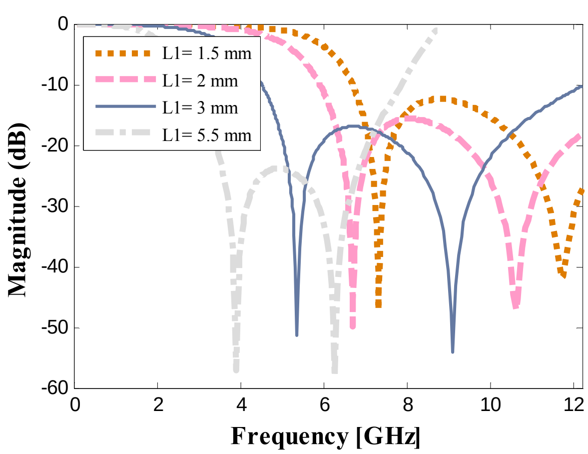


Fig. 5. EM simulated magnitude response of S_{12} as the function of L_1 for the FCTCMRC.

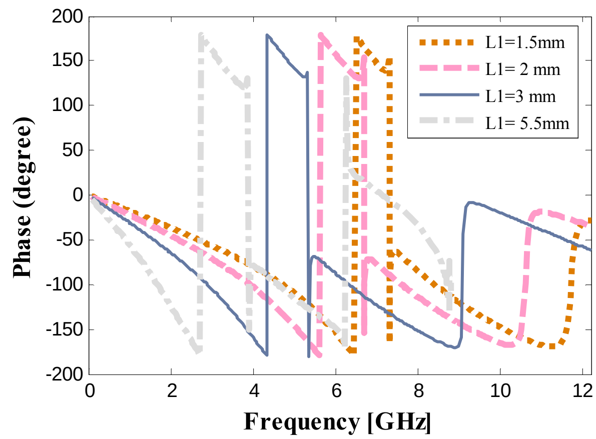


Fig. 6. EM simulated phase response of S_{12} as the function of L_1 for the FCTCMRC.

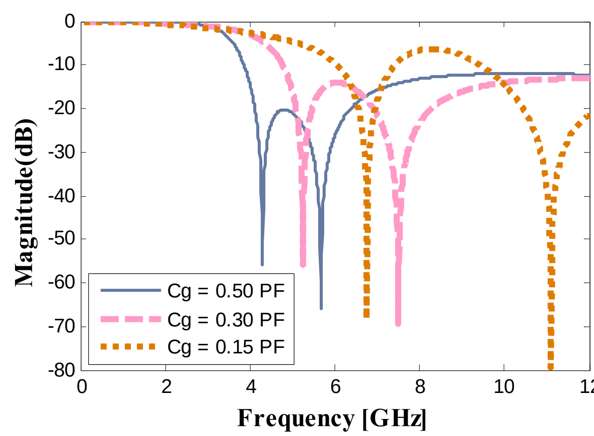


Fig. 7. Simulated response of S_{12} as the function of C_g for the simplified LC equivalent circuit.

III. SIMULATION AND MEASURMENT RESULTS

The proposed power divider is fabricated on RT/Duroid 5880, a substrate with dielectric constant of 2.2, thickness of 0.381 mm, and loss tangent of 0.0009. A photograph of the fabricated power divider with a center frequency fixed at 2 GHz for nth harmonic suppression is shown in Fig. 8. The overall dimension of the circuit is about 2.8 cm × 2.4 cm. The S-parameters are measured using an Agilent 8722ES network analyzer. Figures 9 to 12 illustrate the simulated and measured S-parameters of the proposed power divider. As seen, the simulated and measured results are in good agreement.

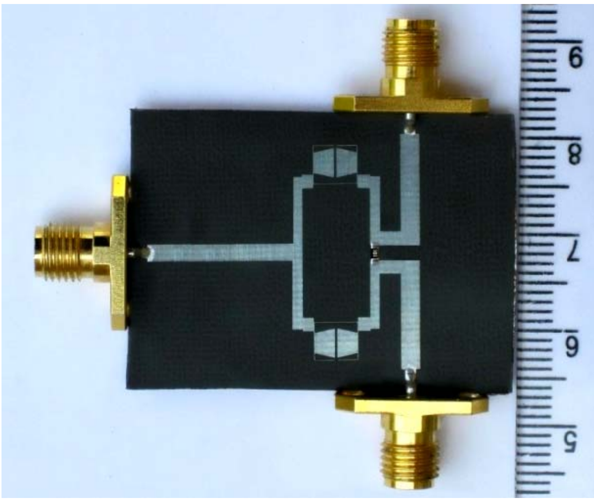


Fig. 8. Photograph of the proposed power divider.

The central frequency of the power divider is located at 2 GHz. At the central frequency, the measured input and output return losses are 48 dB and 44 dB, respectively. It can be seen in Fig. 11 that, the proposed power divider impressively suppresses harmonics, which has an ultra wide stop-band bandwidth (6 GHz – 12 GHz) with a minimum attenuation level of 24 dB. The S_{12} response of the conventional Wilkinson power divider is also shown in Fig. 11.

Figure 12 depicts the simulated and measured isolation of the two output ports. The measured isolation between port two and three is about 45 dB.

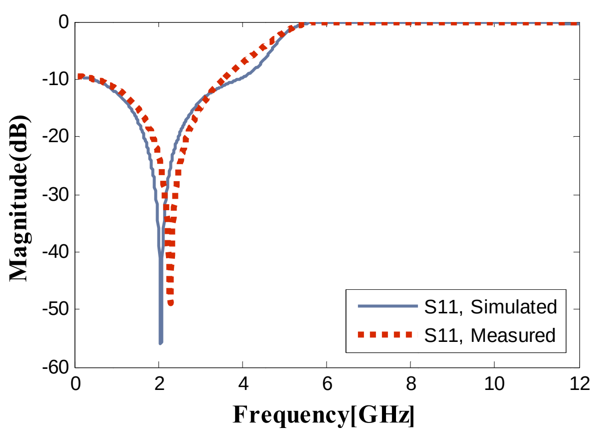


Fig. 9. Measured and simulated response of S_{11} for the fabricated power divider.

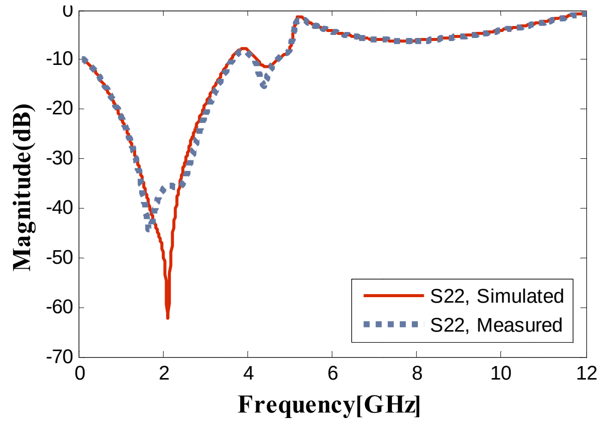


Fig. 10. Measured and simulated response of S_{22} for the fabricated power divider.

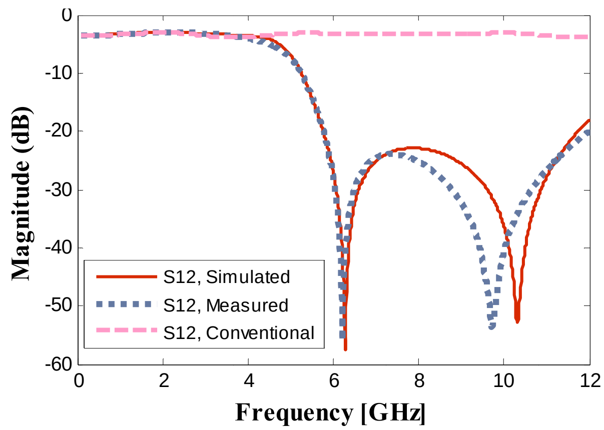


Fig. 11. Measured and simulated response of S_{12} for the fabricated power divider.

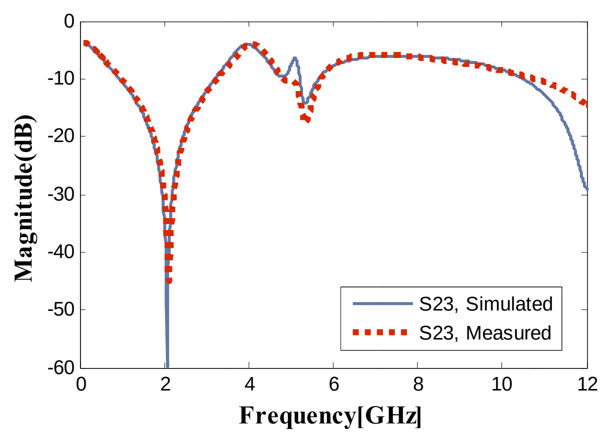


Fig. 12. Measured and simulated response of S_{23} for the fabricated power divider.

A comparison of the power dividers for nth harmonic suppression and λ/4 reduction is summarized in Table 1. The results show that this work presents a fair dimension decrement with superior harmonic suppressions as compared to the reported works.

Table 1: Performance comparison of the proposed power divider with other works.

Ref.	Freq.	λ/4 Line Reduction	Nth Harmonic Suppression
[3]	2.4 GHz	34.5 %	3rd 32.5 dB 5th 12 dB
[5]	2.65 GHz	-	3rd 29 dB 5th 34 dB
[6]	2.05 GHz	-	3rd 44 dB
[7]	1.5 GHz	9.1 %	2nd 18 dB 3rd 15 dB
This work	2 GHz	29.3%	3rd 53 dB 4th 25 dB 5th 56 dB 6th 20 dB

IV. CONCLUSION

In this paper, a novel power divider for nth harmonic suppression is proposed and implemented. By employing the microstrip FCTCMRC, a novel circuit configuration is presented with a smaller size and better harmonic suppression. With the presented method unwanted harmonics can be easily suppressed with high level of attenuations. As the measured results show, the magnitude values of S_{11}, S_{22}, S_{12}, and S_{23} at 2 GHz are 48 dB, 45 dB, 3.1 dB, and 45 dB, respectively. Furthermore, this power divider has an ultra wide stop-band bandwidth (6 GHz – 12 GHz) with a minimum attenuation level of 24 dB, which suppresses 3^{rd} to 6^{th} harmonics simultaneously. The proposed technique can be widely used to reject harmonics and miniaturize circuit dimensions in various microwave circuits such as power amplifiers, oscillators, mixers, and frequency multipliers.

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