

A meander coupled line wideband power divider with open stubs and DGS for mobile application

Sivaprakash SOMALINGA CHANDRASEKARAN^{1,*}, Sivanantha Raja AVANINATHAN²,
Pavithra MURUGESAN¹

¹Department of ECE, K.L.N. College of Engineering, Sivagangai District, Tamilnadu, India

²Department of ECE, A.C. College of Engineering & Technology, Karaikudi, Sivagangai District, Tamilnadu, India

Received: 29.03.2016

Accepted/Published Online: 20.06.2017

Final Version: 05.10.2017

Abstract: A novel meander coupled line power divider for wide band operation from 0.5 GHz to 2.5 GHz with reduced size for mobile application is proposed in this paper. The wide band operation of the coupled line power divider is obtained using open stubs and defected ground structures. The folding of the coupled line reduces the size of the power divider. The proposed power divider has 65% of size reduction in comparison with the existing power divider. All the S-parameters such as return loss, insertion loss, and isolation at different ports are simulated and measured. Bandwidth of 2 GHz is obtained. Both the simulated and measured results agree with each other. Hence it is useful for mobile phone application up to 4G.

Key words: Meander coupled line, open stub, defected ground structure, wide band, mobile application

1. Introduction

Power dividers, particularly wide band power dividers, are an important component in recent microwave communication technology. These dividers are of prime application in the area of mobile communication because of their expansion in different generations up to 4G. The power divider designed by Wilkinson [1,2] uses two quarter-wave length lines and operates in a single band. An analytical approach for coupled line power dividers for dual band operation was given by Wu et al. [3]. In this approach the area occupied by the power divider is large due to lengthy coupled lines. Thus, to make it simpler, dual band power dividers are proposed in [4-7]. Dual band operation and compactness of the power divider are achieved by using coupled lines. The coupled line structure for dual band operation was proposed by Park and Yang et al. The broadband coupled line power divider is designed and synthesized in [8]. Further, the folding of the coupled line leads to a miniaturized power divider. The band width of the power divider is increased by using stubs [9] and defected ground structures (DGSs) [10,11]. The effect of open stubs on the power divider is discussed and its equivalent circuit is presented in [12].

In this paper the size of the circuit is reduced by the novel idea of folding the coupled lines. The inclusion of the stub and the DGS leads to the wide band operation of the power divider. Here twofold coupled lines are used along with two resistors to provide better isolation. The coupled lines are folded in such a way that the chip resistors are fixed conveniently in between the two coupled lines. Hence, the size reduction and wide band operation with better results of different S-parameters are obtained. The proposed power divider works in the

*Correspondence: similinum@gmail.com

frequency range 0.5 GHz to 2.5 GHz with the size measuring 26 × 31 mm. For the fabricated power divider S-parameters S_{11} , S_{22} , S_{33} , and S_{32} are below -10 dB in this frequency range and S_{21} and S_{31} are between -3.4 and -4.7 dB.

2. The circuit structure and theory

The top and bottom layout of the proposed power divider is shown in Figure 1, in which a twofold coupled line is used. The impedance matching is obtained using an open circuited stub. The open circuited stubs are simpler than short circuited stubs because no via holes are used. The DGS with the stub gives the wide band operation of the power divider.

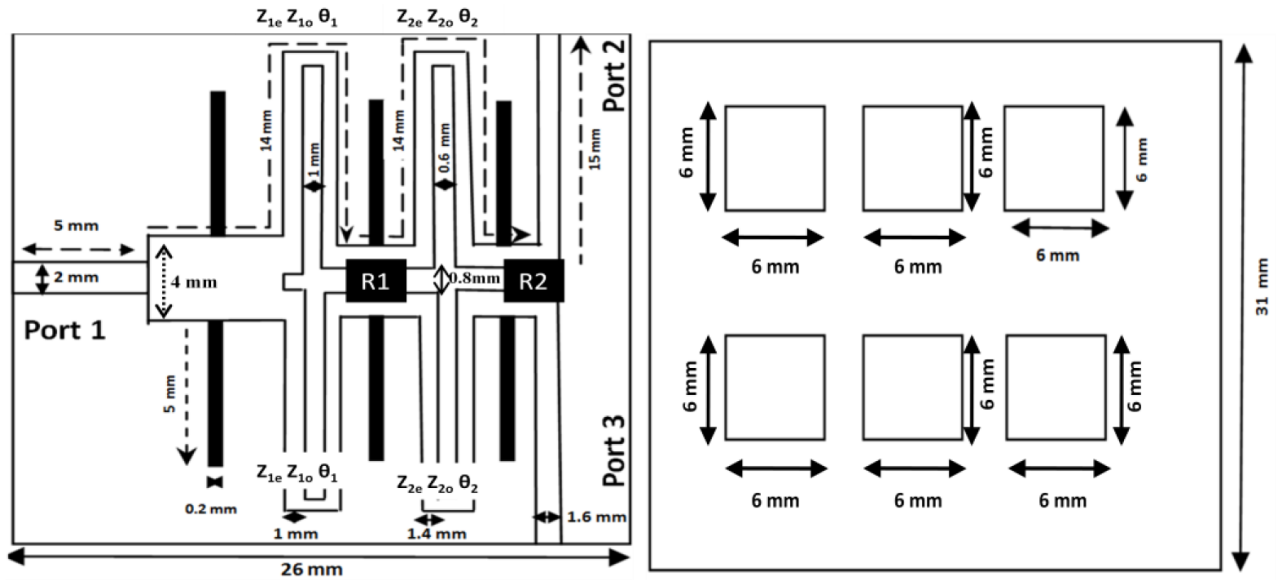


Figure 1. Proposed top and bottom layout of the wide band meander coupled line power divider.

The odd and even mode characteristic impedances of the two coupled lines are calculated from Eqs. (1)-(4) [3].

$$Z_{1e} = Z_0 \sqrt{\frac{(\sqrt{1 + 8 \tan^4 \theta_1} - 1)}{\tan^2 \theta_1}} \tag{1}$$

$$Z_{2e} = Z_0 \sqrt{\frac{(\sqrt{1 + 8 \tan^4 \theta_2} + 1)}{2 \tan^2 \theta_2}} \tag{2}$$

$$Z_{1o} = Z_0 \frac{4}{5} \left(1 + \frac{g}{20}\right) \tag{3}$$

$$Z_{2o} = Z_0 \frac{17}{20} \left(1 - \frac{g}{30}\right) \tag{4}$$

The odd and even mode characteristic impedance is $Z_{1e} = 71.5 \Omega$, $Z_{2e} = 69.91 \Omega$, $Z_{1o} = 45.83 \Omega$, and $Z_{2o} = 38.37 \Omega$. The electrical length is $\theta_1 = 46^\circ$ and $\theta_2 = 133.995^\circ$. The coupling coefficient between two coupled lines is in the range of -5.37 to -6.599 dB.

The values of two isolating resistors are found from Eqs. (5) and (6) [3].

$$R_1 = \frac{2Z_{1o}Z_{2o} \tan^2 \theta_1}{\sqrt{(Z_{1o} + Z_{2o}) \tan^2 \theta_1 [Z_{1o} \tan^2 \theta_1 - Z_{2o}]}} \tag{5}$$

$$R_2 = \frac{2Z_0Z_{2o}^2 (Z_{1o} + Z_{2o}) \tan^2 \theta_2 + 2Z_0^2Z_{2o}\sqrt{(Z_{1o} + Z_{2o}) \tan^2 \theta_2 [Z_{1o} \tan^2 \theta_2 - Z_{2o}]}}{Z_0^2Z_{2o} + (Z_{1o}Z_{2o}^2 - Z_0^2Z_{1o} + Z_{2o}^3) \tan^2 \theta_2} \tag{6}$$

The characteristic impedance of three ports is 50 Ω. The values of isolation resistors are $R_1 = 120 \Omega$ and $R_2 = 1770 \Omega$ as per the equations [2]. However, a practical trial and error experiment gives better results for $R_1 = 100 \Omega$ and $R_2 = 330 \Omega$ than for the original combination of $R_1 = 120 \Omega$ and $R_2 = 1770 \Omega$. The length of the power divider is found by line calculator. The length, width, and spacing of the proposed power divider and stub are given in Table 1. The equivalent circuit for the stub is shown in Figure 2 [12]. The open circuited stubs parallel can be considered as shunt to ground capacitor equivalence.

Table 1. Parameters of proposed power divider.

	Length (mm)	Width (mm)	Space (mm)
Total dimension	26.0	31.0	-
Coupled line 1	14.0	1.0	1.0
Coupled line 2	14.0	1.4	0.6
Stub	5.0	0.2	-
Input port	5.0	2.0	-
Output ports	15.0	1.6	-

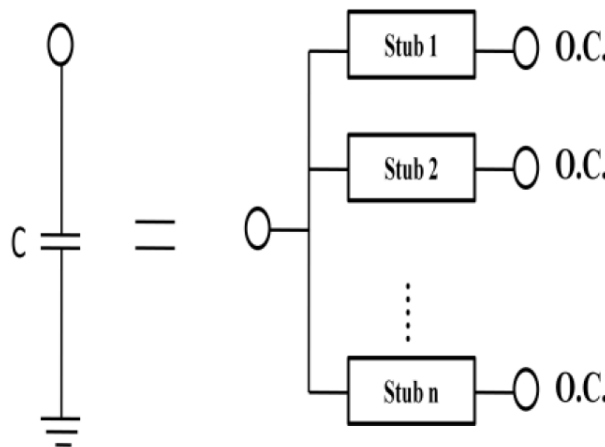


Figure 2. Equivalent circuit of a shunt to ground capacitor with several open stubs in parallel.

The size of the square slots in DGS is arbitrarily chosen as 6 mm × 6 mm. Six such square slots are used in the ground plane. A rectangular DGS on the ground plane increases inductance dominantly while the effective capacitance is extremely small. As a result, a very high line impedance value is obtained. Figure 3 shows the bottom view of the proposed power divider and its simplified transmission line model to determine the characteristic impedance (Z_{DGS}) of the DGS line when port impedance is Z_0 .

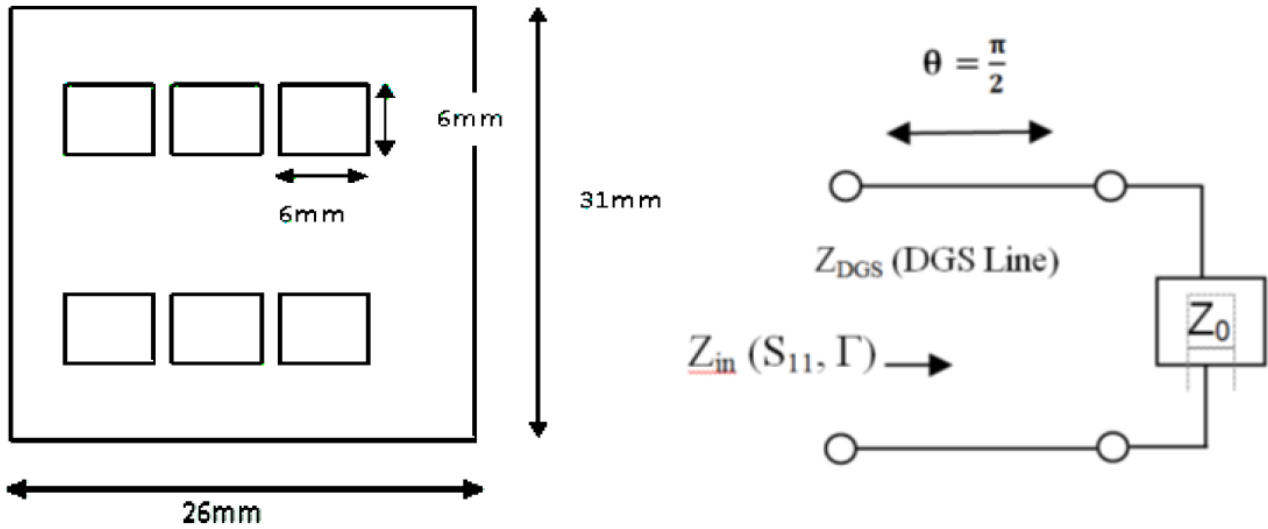


Figure 3. The bottom view of proposed power divider and its transmission line model.

The impedance of the single DGS is calculated from Eqs. (7)–(9) [11]. At the center frequency (f_0), the magnitude of the reflection coefficient (Γ) can be calculated from S_{11} by Eq. (7). Once Γ is known, Z_{in} is calculated by Eq. (8). Finally, the Z_{DGS} is calculated from Eq. (9).

$$|\Gamma| = 10^{\left(\frac{S_{11}[dB]}{20}\right)} \tag{7}$$

$$Z_{in} = Z_0 \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{8}$$

$$Z_{DGS} = \sqrt{Z_{in} Z_0} = Z_0 \sqrt{\frac{1 + |\Gamma|}{1 - |\Gamma|}} \tag{9}$$

For example, if S_{11} is -30 dB, the calculated line impedance of a single DGS will be 51.6Ω at the center frequency f_0 of 1.65 GHz. For six DGSs the total impedance will be 77.4Ω . The introduction of DGSs in the ground plane of the microstrip disturbs shield current distribution and leads to surface wave reduction. This in turn leads to the improvement of band width of operation of the power divider in a new resonant frequency in addition to the existing band.

3. Simulation results

The proposed power divider is designed to operate from 0.5 GHz to 2.7 GHz. The simulation is done using Ansoft Ansys HFSS software. The material chosen for the power divider is Taconic RF-35, which has a relative permittivity (ϵ_r) of 3.5 and thickness of 0.79 mm. The total length and width of the power divider is 26 mm \times 31 mm. The top and bottom layouts of the proposed power divider are shown in Figure 4. Simulation results of various S-parameters such as S_{11} , S_{22} , S_{33} , S_{21} , S_{23} , and S_{31} are shown in Figure 5.

From Figure 5, it is observed that the return loss S_{11} of the power divider is less than -10 dB from 0.5 to 2.7 GHz. Moreover, S_{22} and S_{33} are less than -10 dB from 0.5 GHz to 2.7 GHz. The insertion losses S_{21}

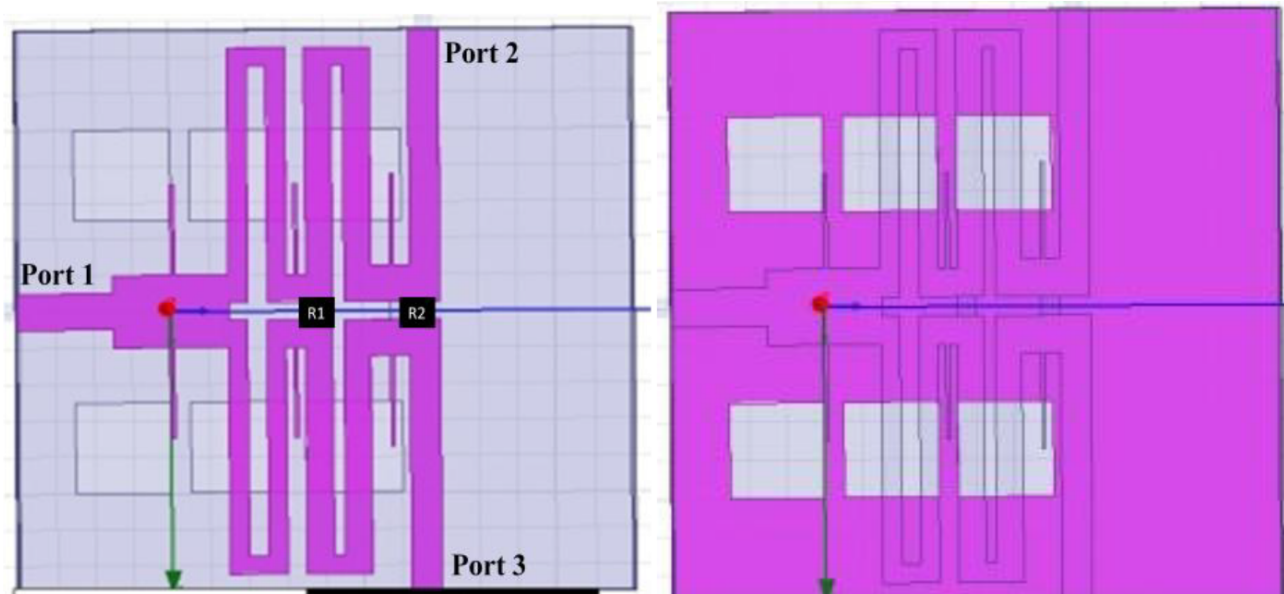


Figure 4. Top and bottom layout of the proposed power divider.

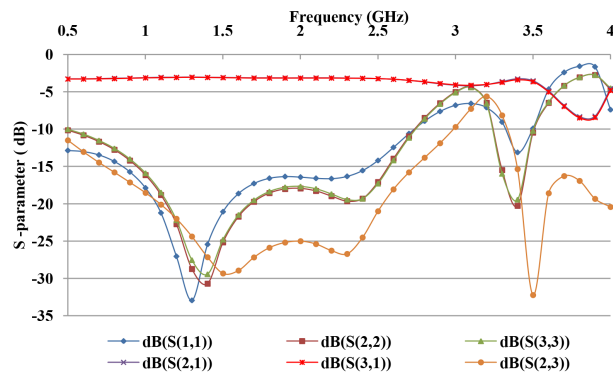


Figure 5. Simulated S_{11} , S_{22} , S_{33} , S_{21} , S_{31} , and S_{23} parameters of the proposed power divider.

and S_{31} of the power divider are -3.0 to -3.4 dB from 0.5 to 2.7 GHz and the isolation S_{23} is less than -10 dB from 0.5 GHz to 2.9 GHz.

4. Measured results

The fabricated power divider is measured using an Agilent FieldFox N9923A vector network analyzer. The top and bottom view of the fabricated proposed power divider is shown in Figure 6. The power divider is with two chip resistors of 100Ω and 330Ω soldered at the places shown in Figure 6. The measurement results of different S-parameters are shown in Figure 7.

The measured results show that the input return loss S_{11} is below -10 dB from 0.5 to 2.5 GHz. The output return losses S_{22} and S_{33} are below -10 dB from 0.5 to 2.5 GHz. The isolation S_{23} is below -10 dB from 0.6 to 3 GHz. The insertion losses S_{21} and S_{31} are -3.4 to -4.7 dB from 0.5 to 2.5 GHz. Therefore, this power divider has good matching, isolation, and insertion loss for wide band operation between 0.5 to 2.5 GHz, which is suitable for mobile communications up to 4G.

Figures 8 and 9 show the comparison between simulated and measured results of S_{11} , S_{22} , S_{33} , S_{21} ,

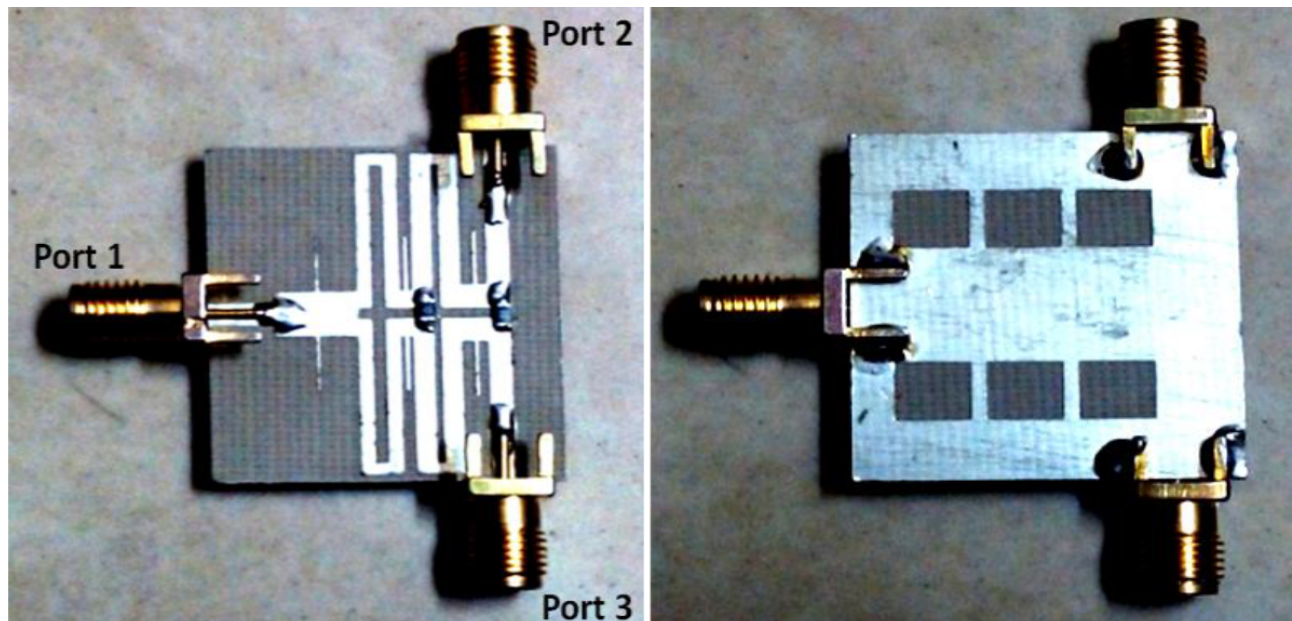


Figure 6. Top and bottom views of the proposed power divider.

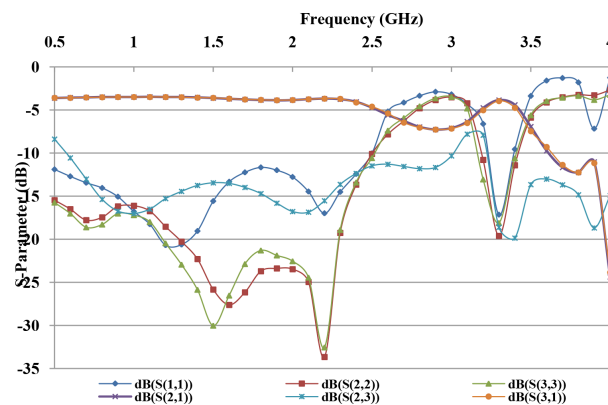


Figure 7. Measured results of S_{11} , S_{22} , S_{33} , S_{21} , S_{31} , and S_{23} parameters.

S_{31} , and S_{23} parameters. These S-parameters S_{11} , S_{22} , S_{33} , and S_{32} are below -10 dB and S_{21} and S_{31} are between -3.4 and -4.7 dB in the frequency range of 0.5 GHz to 2.5 GHz. This analysis shows that the simulated and measured results fully agree with each other.

The existing power divider [3] works in two bands (1.1 and 2.2 GHz) but the proposed power divider works in a wide band from 0.5 GHz to 2.5 GHz. Moreover, the proposed power divider is smaller in size, measuring only about 26×31 mm².

The comparison of the performance of various power dividers is given in Table 2. In this the first power divider [3] is a single layer power divider but the size is large. The second one [7] is a double layered power divider and uses more lumped components like R, L, and C. The third one [11] is a double layered power divider with via holes. Finally, the proposed power divider is a single layered power divider with a wide band of operation, smaller size, only one lumped component, and no other complicated design.

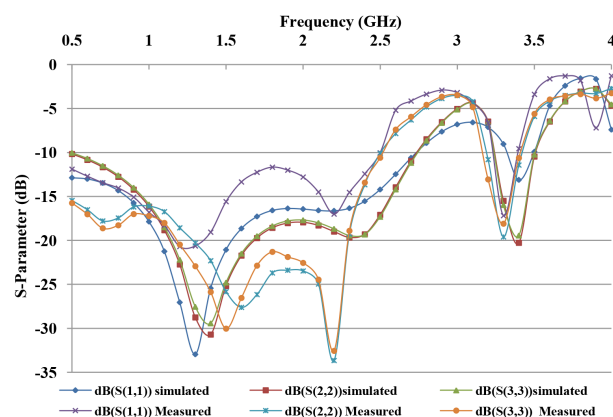


Figure 8. Comparison between simulated and measured results of S_{11} , S_{22} , and S_{33} .

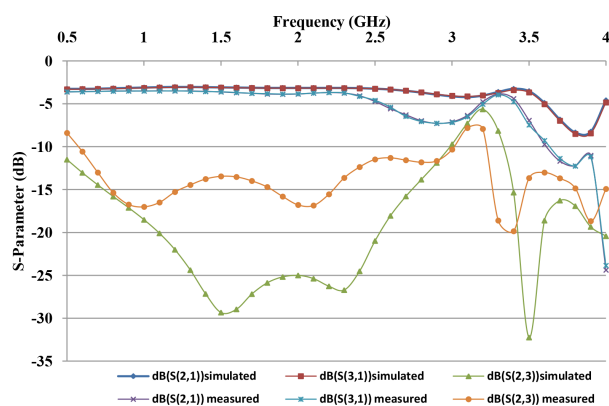


Figure 9. Comparison between simulated and measured results of S_{21} , S_{31} , and S_{23} .

Table 2. Comparison of performance of various power dividers.

Parameter	Wu et al. (2011) [3]	Yang et al. (2008) [7]	Koo et al. (2007) [11]	Proposed power divider
S_{11}	Below -25 dB at 1.1 GHz & 2.2 GHz	Below -20 dB at 0.9 GHz & 1.9 GHz	Below -10 dB from 1.0 to 2.0 GHz	Below -10 dB from 0.1 to 2.7 GHz
S_{22}, S_{33}	Below -25 dB at 1.1 GHz & 2.2 GHz	Below -20 dB at 0.9 GHz & 1.9 GHz	Below -10 dB from 1.0 to 2.0 GHz	Below -10 dB from 0.5 to 2.7 GHz
S_{21}, S_{31}	-3.15 dB for 1.1 GHz & -3.19 dB for 2.2 GHz	Around -3.5 dB at 0.9 GHz & 1.9 GHz	-2 dB for S_{21} & -7.5 dB for S_{31} from 1.0 to 2.0 GHz	-3.29 to -3.45 dB from 0.5 to 2.7 GHz
S_{23}	Below -30 dB at 1.1 GHz & 2.2 GHz	Below -20 dB at 0.9 GHz & 1.9 GHz	Below -10 dB from 1.0 to 2.0 GHz	Below -10 dB from 0.5 to 2.9 GHz
Size of the total power divider	54.0 × 59.0 mm ² (approximately, as per our calculation)	Not given	Not given	26.0 × 31.0 mm ²
Structure	Single layer	Double-sided parallel strip line with R, L, and C lumped components used	Two layer substrate with via holes	Single layer

5. Conclusion

A wideband power divider is simulated, fabricated, measured, and compared in this paper. The folding technique of power divider gives compact size and the performance enhancement is done using stubs and DGS structures. The simulated power divider works well within the frequency range of 0.5 GHz to 2.7 GHz, whereas the fabricated power divider gives good performance over a frequency range between 0.5 GHz and 2.5 GHz. The simulation results represent a good agreement with the measurement results. There is considerable reduction in size as the size of the power divider is 26 × 31 mm² only. The bandwidth of the wide band power divider is 2 GHz. This power divider is very much suitable for mobile communication applications of 2G, 3G, and 4G.

References

- [1] Wilkinson E. An N-way hybrid power divider. *IRE T Microw Theory* 1960; 8: 116-118.
- [2] Pozar DM. *Microwave Engineering*. 4th ed. New York, NY, USA: John Wiley & Sons, Inc., 2011.
- [3] Wu Y, Liu Y, Xue Q. An analytical approach for a novel coupled-line dual-band Wilkinson power divider. *IEEE T Microw Theory* 2011; 59, 2: 286-294.
- [4] Park MJ. Dual-band Wilkinson divider with coupled output port extensions. *IEEE T Microw Theory* 2009; 57: 2232- 2237. Park MJ. Two-section cascaded coupled line Wilkinson power divider for dual-band applications. *IEEE Microw Wirel Co* 2009; 19: 188-190.
- [5] Cheng KKM, Law C. A novel approach to the design and implementation of dual- band power divider. *IEEE T Microw Theory* 2008; 56: 487-492.
- [6] Yang T, Chen JX, Zhang XY, Xue Q. A dual-band out-of phase power divider. *IEEE Microw Wirel Co* 2008; 18: 188-190.
- [7] Ekinge RB. A new method of synthesizing matched broadband TEM-mode three- ports. *IEEE T Microw Theory* 1971; 19: 81-88.
- [8] Chen HD. Broadband CPW-fed square slot antennas with a widened tuning stub. *IEEE T Antenn Propag* 2003; 51: 1982-1986.
- [9] Chiang KH, Tam KW. Microstrip monopole antenna with enhanced bandwidth using defected ground structure. *IEEE Antenn Wirel Pr* 2008; 7: 532-535.
- [10] Koo JJ, Oh S, Hwang MS, Park C, Jeong Y, Lim J, Choi KS, Ahn D. A New DGS unequal power divider. In: *Proceedings of the 37th European Microwave Conference*; October 2007; Munich, Germany: pp. 556-559.
- [11] Deng PH, Guo JH, Kuo WC. New Wilkinson power dividers based on compact stepped-impedance transmission lines and shunt open stubs. *Prog Electromagn Res* 2012; 123: 407-426.