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A Miniaturized Dual-Frequency Wilkinson Power Divider Using Defected Ground Structure

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Abstract— **In this paper, we apply a defected ground structure (DGS) to design a compact dual-frequency Wilkinson power divider (WPD). As the necessary area for dual-frequency Wilkinson power divider has a considerable increment toward single frequency WPD, we have to reduce its size especially in lower frequencies. With using dumbbell DGS, both designed operating frequencies are significantly lowered and consequently 49% size reduction for both operating frequencies is achieved. Simulated and measured results are presented and show good agreement.**

Keywords- Wilkinson power divider; dual-frequency; defected ground structure; size reduction.

I. INTRODUCTION

Power dividers have a widespread application in microwave and millimeter-wave circuits such as power amplifiers, mixers, and antenna systems. In recent years, there has been an essential necessity for dual-band power dividers, which are used in multiband mobile phones [1]-[5].

In [6], a Wilkinson power divider operating at the desired frequency f_1 and its first even harmonic $2f_1$ has been presented. In [1], a dual frequency Wilkinson power divider operating at two arbitrary different frequencies has been proposed. In [2], [3], [7] and [8] different schematics of dual-frequency Wilkinson power dividers have been presented.

Recently, the Defected Ground Structure (DGS) has been used in different microwave and millimeter-wave circuits for various applications such as size reduction [9], harmonic suppression [10] and improving S-parameters [9]. With implementing DGS, size reduction of the microstrip line can be obtained by increasing the effective inductance of the transmission line which leads to longer electrical length and consequently smaller size of circuit [1].

In this paper, we use a dumbbell DGS unit in order to reduce the size of the dual-frequency Wilkinson power divider.

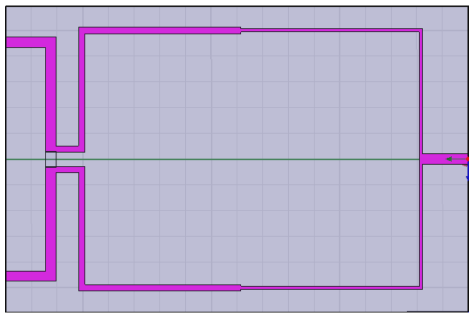


Figure 1.A dual-band Wilkinson power divider for $f_1 = 0.94\,GHz$ and $f_2 = 2.5\ GHz$.

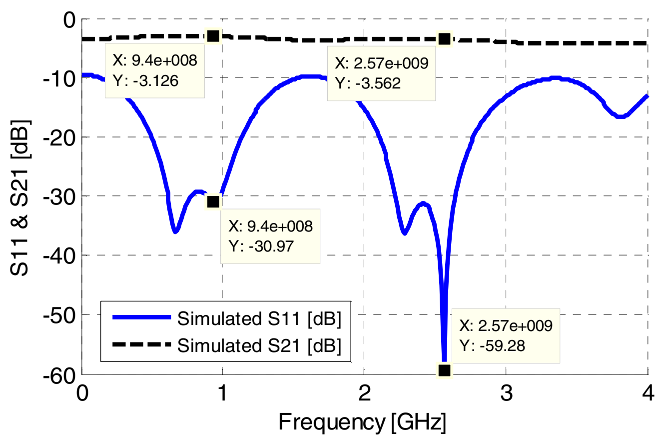


Figure 2. Simulation result of S-parameters (S_{11}, S_{21}, S_{31}) for the dual-frequency Wilkinson power divider.

As can be seen in the proposed Wilkinson power divider in [1], we need two transmission lines having more length compared with that of single-frequency Wilkinson power divider. Therefore, it is more necessary to reduce the size of dual-frequency WPDs. In section II, design procedure, implementing details of DGS for size reduction and the proposed techniques for improvement of S-parameters are explained. In section III, a new equivalent circuit for DGS are presented and finally the effect of the dimensions are studied.

I. DESIGN PROCEDURE

To design the miniaturized dual-band WPD, we have employed the two section dual-band WPD, introduced by Lei Wu in [1].

We design the WPD for operating frequencies $f_1 = 0.94\,GHz$ and $f_2 = 2.5\,GHz$. According to that solution, the WPD parameters can be obtained at following conditions [1]:

$$l_1 = l_2 = \frac{n\pi}{\beta_1 + \beta_2} \tag{1}$$

$$Z_2 = Z_0\sqrt{\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + 2}} \tag{2}$$

$$Z_3 = \frac{2Z_0^2}{Z_2} \tag{3}$$

$$\alpha = (\tan(\beta_1 l_1))^2 \tag{4}$$

$$\beta = \frac{2\pi}{\lambda} \tag{5}$$

In previous equations, n is a positive integer.

The designed dual-band WPD is shown in Fig.1. The parameters S_{11}, S_{21} and S_{31} are shown in Fig. 2. As illustrated, our elementary WPD is operating at $f_1 = 0.94GHz$ and $f_2 = 2.5GHz$. It indicates that we have an equally divided and transmitted signal to the output ports at our both operating frequencies. Also S_{11} shows good performance. We have an input return loss of $-30dB$ at $0.94GHz$ and $-66dB$ at $2.58GHz$. For the first band, the 10% bandwidth has S_{11} lower than $-28dB$ and for the second band S_{11} is lower than $-22dB$.

As we know for achieving to lower operating frequencies, we need to have longer area for greater values of operating wavelength, but by implementing DGS, f_1 is lowered to $0.57GHz$ and f_2 to $1.18GHz$ without any needs for increasing area. In fact, DGS disturbs the current path in the ground plane and so decreases phase velocity. This causes an increase of effective dielectric constant and decrease of the effective wavelength. Consequently characteristic impedance will be increased. So by designing a proper DGS we can decrease the operating frequencies because of decreasing effective wavelength and S-parameters can be controlled by adjusting characteristic impedance of transmission lines by changing dimensions of DGS. In this case, the new operating frequencies i.e. f_1' and f_2' are respectively $0.6f_1$ and $0.47f_2$. Consequently, lowered frequencies are achieved without using larger quarter wavelength transmission lines, which must be as twice as the previous ones. $(l_1' = l_2' = \frac{c}{2(f_1' + f_2')} \approx \frac{c}{f_1 + f_2} \approx 2l_1)$

In the designed dual-band WPD, the characteristic impedance and length of two sections are derived from equations 1-3 of [1]. The substrate is RO4003 with thickness of $0.813mm$, a relative permittivity of 3.38 and a conductor thickness of $0.05mm$. The total area is $9.8 \times 6.6cm^2$. The proposed dual-band WPD with DGS is illustrated in Fig. 3. The dimensions of DGS are $A = 0.5mm$, $B = 1.2mm$, and $C = D = 4mm$. We use Ansoft-HFSS to simulate the WPD.

II. EQUIVALENT CIRCUIT OF DUMBBELL DGS

A new circuit model has been developed to characterize the dumbbell DGS behavior. It can model the DGS frequency response both in the used frequency band in this design ($1GHz - 3GHz$) and for resonance frequency which is $10GHz$ for proposed dimensions. The proposed circuit model has noticeably better performance than the usual RLC model. Fig. 4 shows the proposed equivalent circuit. L_0 and C_0 represent the inductance and capacitance caused by current disturbances in the ground plane [11]. R_0 represents radiation losses and controls input return loss magnitude. In order to have a wider resonance band, another LC (i.e: L_1C_1 and L_2C_2) has been implemented in both sides which cause circuit symmetry. Finally C_3 and C_4 represent the fringing field caused by discontinuity area. The corresponding values of $R_0, L_0, C_0, L_1 = L_2, C_1 = C_2$ and $C_3 = C_4$ are respectively $180\Omega, 0.42nH, 0.59pF, 0.3nH, 0.19pF$ and $1pF$ after optimization. Figs. 5 and 6 show S-parameters of the DGS unit and both proposed and conventional RLC equivalent circuits.

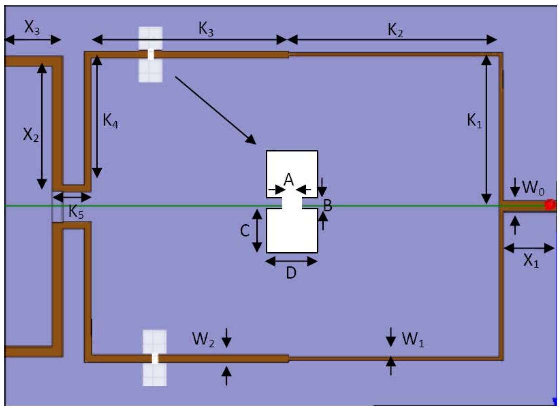


Figure 3. A dual-band Wilkinson power divider with dumbbell DGS for $f_1 = 0.57GHz$ and $f_2 = 1.2GHz$.

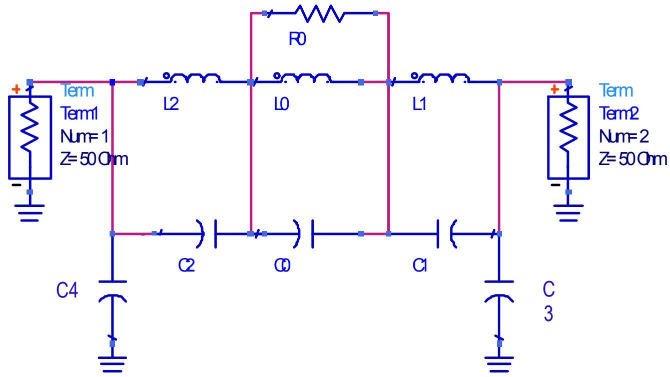


Figure 4. The proposed equivalent circuit of the dumbbell DGS.

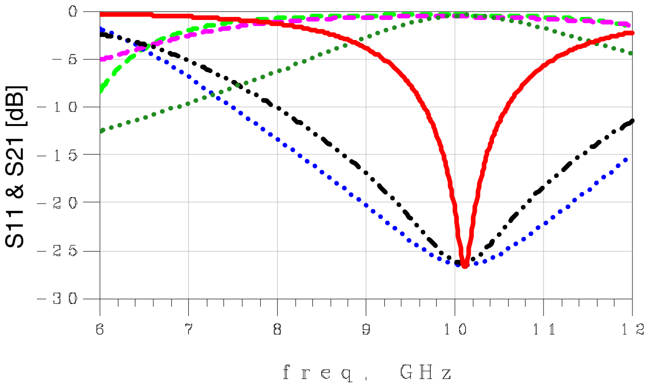


Figure 5. EM, RLC and proposed circuit simulation results of dumbbell DGS in resonant frequency band.

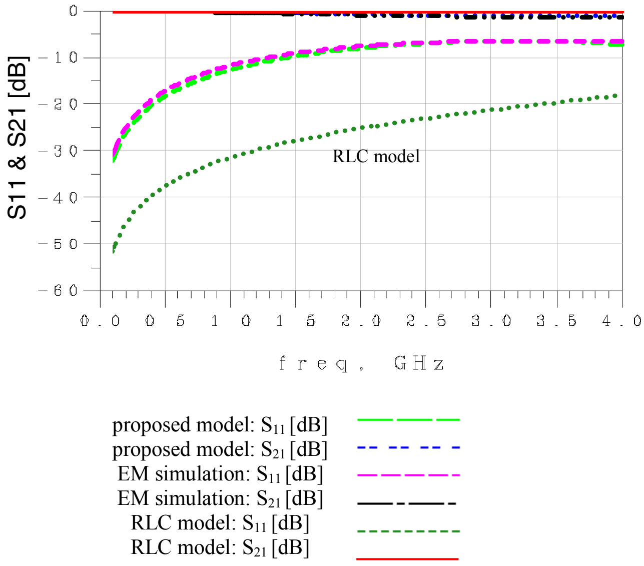


Figure 6. EM, RLC and proposed circuit simulation results of dumbbell DGS in operating frequency band.

Figs. 5 and 6 show that the results of the proposed model are well matched with those of the EM simulation both in the resonant frequency as well as out of resonance frequency band.

In order to reduce the operating frequencies without increasing the length of transmission lines, a dumbbell DGS has been used. The size of DGS and its location have been chosen in order to reach a good performance at frequencies $f_1 = 0.57GHz$ and $f_2 = 1.18GHz$. Scattering parameters *i.e.* S_{11}, S_{21} and S_{31} are shown in Fig. 7. The input return loss is $-27dB$ for f_1 and $-33dB$ for f_2. For the first band, the 10% bandwidth has S_{11} lower than $-25dB$ and for the second band S_{11} is lower than $-29dB$.

Table 1 contains the values of designed parameters. The values of chip resistor for output ports isolation is 100Ω .

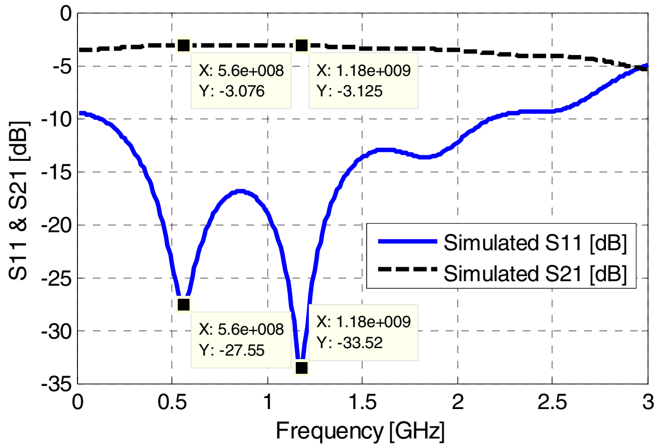
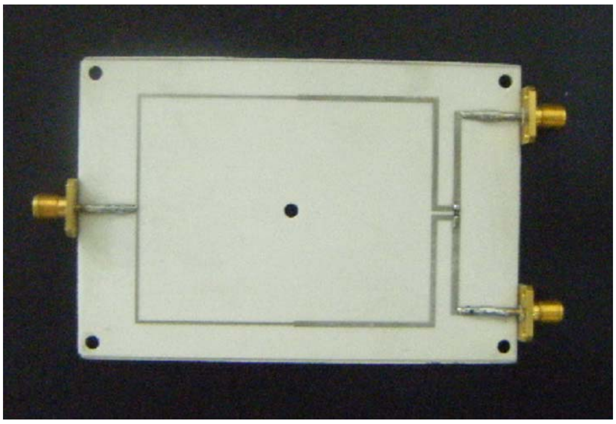


Figure 7. Simulation result of S-parameters (S_{11},S_{21},S_{31}) for the dual-frequency Wilkinson power divider with DGS.

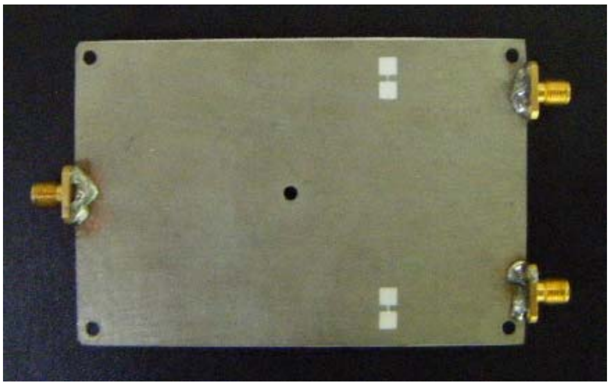
Table I. Values of design parameters

Design parameters values			
Parameter	***Designed value (mm)***	***Parameter***	***Designed value (mm)***
W_0	1.65	K_3	31
W_1	0.6	K_4	24
W_3	1.2	K_5	5
X_1	8.9	A	0.5
X_2	21.1	B	1.2
X_3	7.8	C	4
K_1	25	D	4
K_2	35		

Both dual-frequency WPDs which are with and without DGS, are fabricated. The top and bottom view of the fabricated dual-frequency WPD with dumbbell DGS and its measurement setup is respectively shown in Figs. 8 and 9. In Figs. 10 measured and simulated S_{11} and S_{21} parameters have been shown for WPD without DGS. The measured S_{11} parameter is $-58dB$ at $f_1 = 0.97GHz$ and $-21dB$ at $2.57GHz$. In Figs. 11 and 12, measured and simulated S-parameters for WPD with DGS have been presented. As shown, fabricated S_{11} is $-28.6dB$ at $0.5GHz$ and $-63.8dB$ at $1.1GHz$. And fabricated S_{22},S_{23} are $-16.3dB$ at $0.56GHz$ and $-25.6dB$ at $1.18GHz$.



(a)



(b)

Figure 8. Fabricated 3-dB dual-band Wilkinson power divider with dumbbell DGS. (a) Top view. (b) Bottom view.

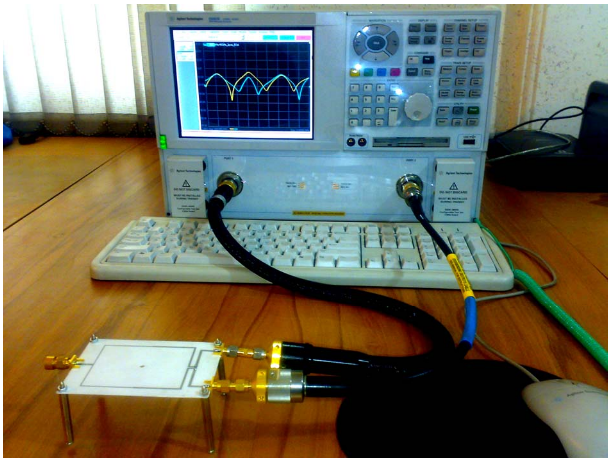


Figure 9. Measurement setup of fabricated dual-band Wilkinson power divider with dumbbell DGS.

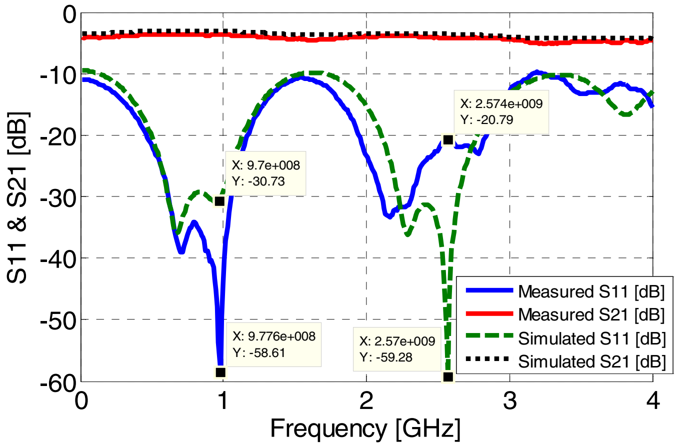


Figure 10. Measured and simulated S-parameters of dual-frequency WPD without DGS. (S_{11} and S_{21}).

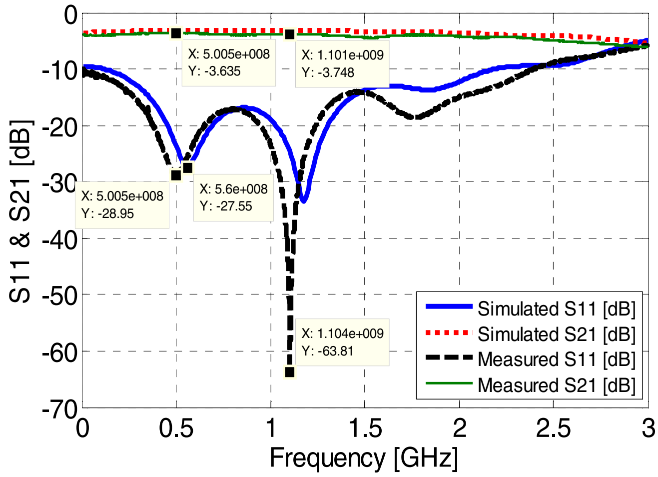


Figure 11. Measured and simulated S-parameters of dual-frequency WPD with DGS. (S_{11} and S_{21})

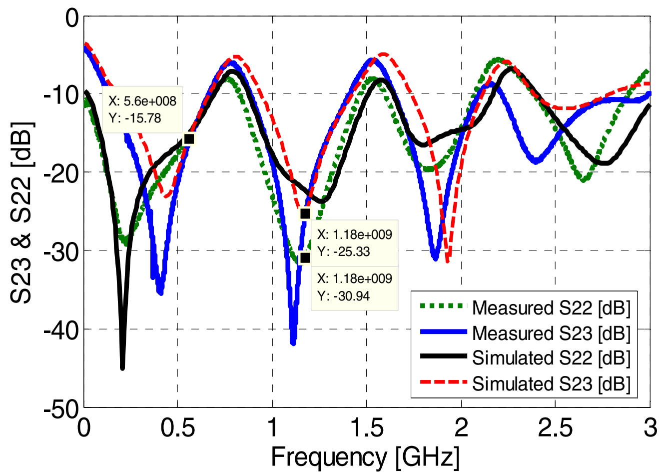


Figure 12. Measured and simulated S-parameters of dual-frequency WPD with DGS. (S_{22} and S_{23})

In order to study the effects of DGS dimensions in WPD operation, we analyze two different cases. At first C and D are kept constant and A is changed. As can be inferred from Fig. 13, the gap (A) does not shift resonance frequency and just affects S_{11} amplitude. Second, as shown in Fig. 14, A is kept constant and square dimensions (C=D) have been changed. In this case, with increment of C=D, the first operating frequency is decreased and the second operating frequency is increased. So the desired frequencies can be achieved by controlling the square size. Besides, its effect on S_{11} amplitude should be considered in selecting proper dimensions.

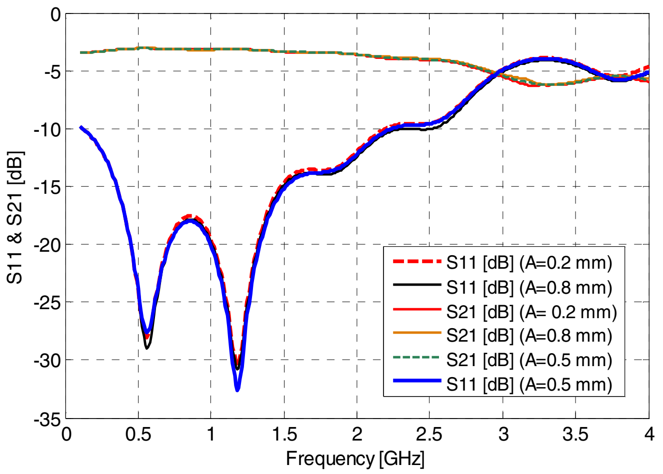


Figure 13. Simulated S-parameters for different values of A.

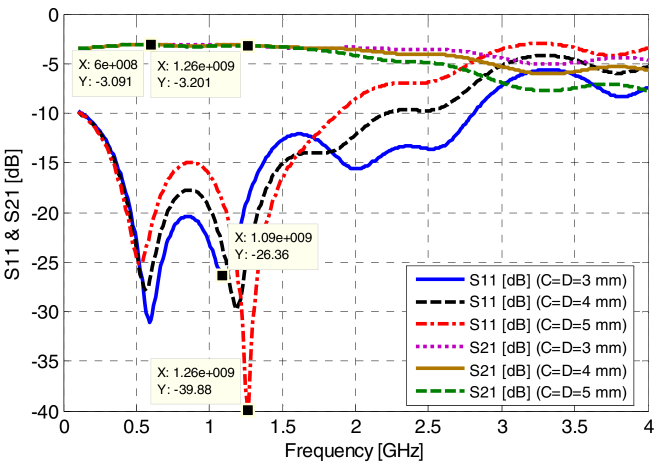


Figure 14. Simulated S-parameters for different values of C=D.

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CONCLUSION

This paper has combined dumbbell defected ground structure with Dual-band Wilkinson power divider for the first time in order to reduce its size and improving its operation, which previously has been done for single-band WPD. A new equivalent circuit has been proposed for modeling both operating frequency band and resonance band. The designed and fabricated WPD fulfills an equal power split and proper input and output return loss at the half frequency than the those of the primary one without increasing its size and just by implementing dumbbell DGS.

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