Progress In Electromagnetics Research Letters, Vol. 4, 113–120, 2008

MINIATURIZATION OF WILKINSON POWER DIVIDERS BY USING DEFECTED GROUND STRUCTURES

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Abstract—It is proposed that the application of defected ground structures (DGS) and electromagnetic bandgap (EBG) reduce the phase velocity, increase effective permittivity of microstrips and reduce the effective the wavelength which eventually lead to the reduction of overall length of Wilkinson power dividers. Furthermore, the adjacent strip lines may approach each other, which cause coupling problems. The undesired coupling maybe cancelled by connecting a capacitance in parallel with the isolation resistor of Wilkinson power divider. Application of DGS and EBG will not only reduce the dimensions of the divider, but also improves its scattering parameters.

1. INTRODUCTION

Power dividers vary widely with particular advantages and disadvantages. The Wilkinson power divider was invented in 1960 [1] and has completely matched output ports with sufficiently high isolation between them. This device is also potentially lossless provided that no reflected power from output ports enters into it. This divider has wide applications in microwave circuits and antenna feeds, but it has a narrow bandwidth, which has the best performance at a center frequency. Several schemes have been devised to increase its bandwidth [2, 3]. The even and odd mode analysis was employed for a single section Wilkinson power divider [4]. It should be noted that the even and odd mode analysis is useful for axially symmetric circuits [3].

In recent years, several schemes have been proposed to decrease the size of transmission lines in order to facilitate their application in microwave integrated circuits (MICs) and monolithic microwave integrated circuits (MMICs) [5–7]. The procedure that is employed in this paper to decrease the length of two strips uses a defected ground structure (DGS) and electromagnetic bandgap (EBG). DGSs are structures which are realized by defecting ground planes [8]. If DGSs are repeated periodically, it is Known as electromagnetic bandgap (EBG). The effect of DGSs is to place parallel inductance and capacitance in the lumped model which adds a pole to the transfer function and results in a resonant frequency. DGSs affect parameters of circuit that can be expressed as: making an interference in the fields of ground plane, increasing permittivity, increasing effective inductance and capacitance properties in transmission lines and making a unipolar low pass filter [9].

In this paper, it is proposed to reduce the size and dimensions of the Wilkinson power divider by the application of DGSs and EBGs. However, as a result the coupling between conducting strips increase, which leads to the difference between the odd and even permittivities and phase velocities. It is proposed to connect a capacitor across the resistor in the divider,to equalize the even and odd velocities. To demonstrate the performance and effectiveness of the proposed circuit configuration, two examples of the design of Wilkinson power divider are presented for the operating frequencies of 1.3 GHz and 5 GHz.

2. DESIGN PROCEDURE

The objective of this paper is to investigate the application of defected ground structures (DGSs) and electromagnetic bandgaps (EBGs) on the design of Wilkinson power divider (see Fig. 1) [10–16]. DGSs increase the effective values of dielectric constant of substrates (ε_{eff}), decrease the wavelength and eventually decrease the overall length of the Wilkinson divider. Furthermore, we propose a design procedure for placing the two arms of divider as close together as possible, which further decreases its size (see Figs. 2 and 3). By this configuration

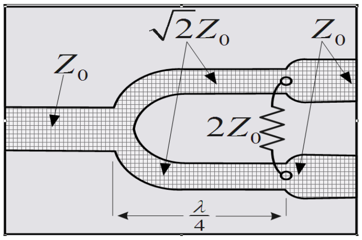

Figure 1. Wilkinson power divider with characteristic impedance equal to 50 Ω ($Z_0 = 50\,\Omega$).

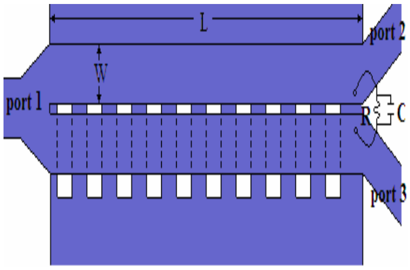

Figure 2. Wilkinson power divider at 1.3 GHz with EBG.

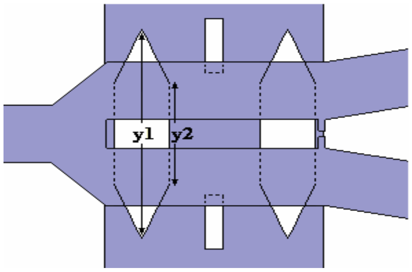

Figure 3. Wilkinson power divider in 5 GHz with DGSs.

the DGSs may be placed under both arms of the divider, and the total number of DGSs is decreased. Initially, the divider is designed by the conventional method, based on the even mode, ignoring the mutual coupling between the arms. (The design based on the odd mode causes a frequency shift.) Then connecting a capacitor in parallel with the resister connected at the two output terminals of divider, equalizes the odd and even phase velocities and consequently there would be no distinction between the odd and even mode couplings. When the two strips are close together, there is strong coupling between them [17].

Suppose that C_{11} and C_{22} are the capacitances of strips 1 and 2 with respect to the ground plane, respectively and C_{12} is the capacitance between the two strips for the odd mode. Then, the even and odd mode capacitances are [18, 19]:

$$C^e = C_{11} = C_{22} \tag{1}$$

$$C^o = C_{11} + 2C_{12} = C_{22} + 2C_{12} \tag{2}$$

Therefore:

$$C_0^o > C_0^e \tag{3}$$

However, if C_{12} is ignored when there is substrate, then

$$C_d^o \approx C_d^e \tag{4}$$

If the capacitances in the presence and absence of dielectric substrate are denoted by C_d and C_0, respectively, then

$$C_d = \varepsilon_{eff} C_0 \;\Leftrightarrow\; C_0 = \frac{C_d}{\varepsilon_{eff}} \tag{5}$$

where ε_{eff} is the effective permittivity of the substrate with ε_r. Then combining Eqs. (3) and (5), we conclude:

$$\frac{C_d^o}{\varepsilon_{eff}^o} > \frac{C_d^e}{\varepsilon_{eff}^e} \tag{6}$$

Combining Eqs. (4) and (6), we have

$$\varepsilon^o_{\mathit{eff}} < \varepsilon^e_{\mathit{eff}} \tag{7}$$

Consequently,

$$V^o_{ph} > V^e_{ph} \tag{8}$$

The same conclusion may be derived by noting that there is more leakage of electric flux in the air for the odd mode than the even mode. Consequently, $\varepsilon^o_{\mathit{eff}}$ is less than $\varepsilon^e_{\mathit{eff}}$. If a capacitor is connected between the divider output terminals (in parallel with the resistor), it has no effect on the even mode (because the output terminals are at the same potential), but it produces a phase lag for the odd mode.

Consequently, the difference between odd and even phase velocities is compensated and the coupling effects are cancelled out.

Now, we design the divider for the even mode at frequency 1.3 GHz by the conventional method and decrease its length by about 30%.

$L = 29\,\mathrm{mm}$, $W = 2.25\,\mathrm{mm}$, distance between two strip and thickness of substrate are 0.5 and 1.57 mm, respectively.

For the even mode, two impedances of 100 and 50 Ω are matched by a line of characteristic impedance $50\sqrt{2}$ and length $\lambda/4$ (or electrical length 90°). We intend to decrease the physical length of the line for the same electrical length. This is achieved by inserting DGSs in the ground plane.

DGSs lead to the increase of the path of current, decrease of the effective phase velocity (V_p), increase of the effective permittivity ($\varepsilon_{\mathit{eff}}$) and eventually decrease of the effective wavelength (λ_{eff}). The DGSs are selected as rectangular slots cut in a row in the ground plane under the power divider. Initially, the dimensions of slots and their spacings are selected arbitrarily or randomly. Appropriate source and load impedances are connected to the divider. Then, the resulting configuration of the divider is analyzed by the HFSS software to obtain the scattering parameters S_{11} and S_{12}. The parameter S_{11} indicates the reflection from the divider which should be nearly zero and S_{12} indicates the out power, including the 90° phase shift. The parameters (divider and DGS dimensions) are changed step by step to obtain the design specifications, namely minimization of S_{11} and realization of the division ratio S_{12}. This procedure eventually gives the microstrip line widths and DGS dimensions.

The S parameters of the divider are drawn in Fig. 4 for the two cases of before and after cutting and introducing DGSs. It is seen that the application of DGS has both reduced the size of divider and also has improved its overall performance. At frequency 1.3 GHz, the initial length was 29 mm and was decreased by 30% to 20 mm. The various parameters are:

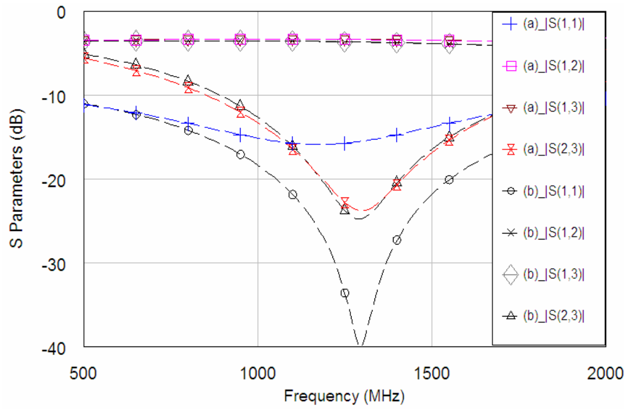

Figure 4. *S* parameter curves before and after using EBG designed at 1.3 GHz. Curves designed by **a** belong to before those denoted by **b** belong to after using EBG.

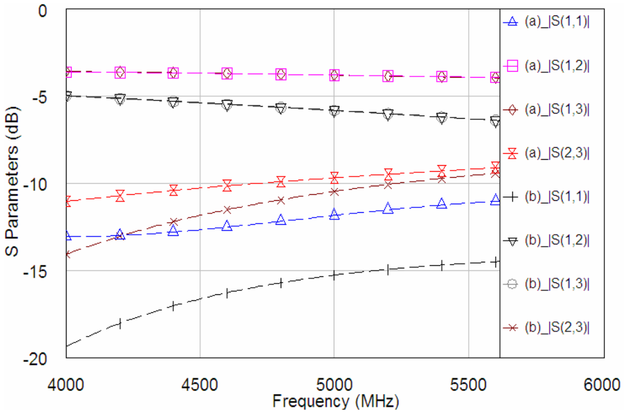

Figure 5. *S* parameter curves before and after using DGSs designed at 5 GHz. Curves designed by **a** belong to before those denoted by **b** belong to after using DGSs.

$L = 20\,\text{mm}$, $W = 3\,\text{mm}$, distance between two strips is 0.5 mm, thickness of substrate is 1.57 mm with permittivity equal to 4.4 and length and width and distance of DGSs from each other are 6, 1 and 1 millimeters, respectively.

The *S* parameters of a second divider as designed for 5 GHz are drawn in Fig. 5. Its initial length was 7.7 mm and was decreased by 20% to 6 mm. The various parameters are:

$L = 6\,\text{mm}$, $W = 2\,\text{mm}$, $y1 = 7\,\text{mm}$, $y2 = 3\,\text{mm}$, thickness of substrate is 1 mm with permittivity equal to 4.4 and width and distance of DGSs from each other are 1.5 and 2.5 millimeter respectively.

The performance of second example at higher frequencies is not satisfactory, since DGSs do not operate properly. This phenomenon may be interpreted as follows:

Since at higher frequencies, the length of divider is decreased, the number of DGSs, which may be cut in the ground plane, also decreases. Moreover, a capacitance may be attributed to a DGS, which increases with the decrease of its size. Therefore, at higher frequencies the equivalent impedance of DGS approaches zero, leading to the effective stoppage of operation of DGS. As the size of DGS decreases, the surface current in the vicinity of DGS current passes through it in the form of displacement current. For the DGS to properly operate at higher frequencies, it is necessary to decrease its equivalent capacitance by increasing its width. But in this case, it tends to radiate and increase its losses. Consequently, the application of DGS at higher frequencies may not be effective due to the shortening of line lengths and decrease of the number of DGSs and also increase of radiation losses. One side of the rectangular slots is tapered in triangular shape to limit the radiation through it.

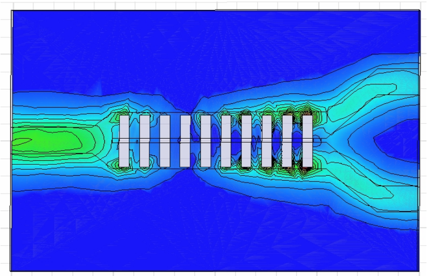

Figure 6. Magnitude contours of surface current on ground plane for 1.3 GHz.

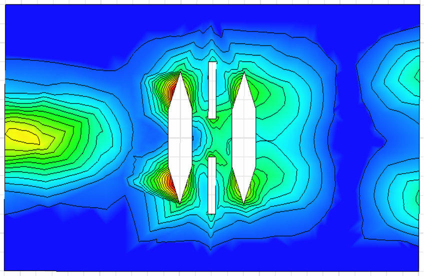

Figure 7. Magnitude contours of surface current on ground plane for 5 GHz.

3. CONCLUSION

In this paper it is shown that the application of defected ground structures (DGSs) in the Wilkinson power divider results in the reduction of its size, both its length and its width. However, this effect is more pronounced at lower microwave frequencies. At higher frequencies, the reduction of divider size may not be possible by the application of DGSs.

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