A Miniaturization of 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 miniaturized dual-band Wilkinson power divider (WPD). Dual band Wilkinson power divider consists of two different transmission lines hence it has considerable size increment in comparison with single frequency Wilkinson power divider. For a compact device it is necessary to reduce the size of dual band Wilkinson power divider. By using slow wave effect property of defected ground structure (DGS) we have reduced the size of dual band Wilkinson power divider by 14.8%.

Key words: Wilkinson power divider; dual-frequency; defected ground structure; size reduction

I. INTRODUCTION

The power dividers and combiners are very important components for microwave power amplifiers, balanced mixers and antenna feeds. The conventional Wilkinson Power Divider that only operates at one design frequency is not suitable for some dual band operations, as seen in the downlink operation of the Global System of Mobile communication band (GSM) and at the Personal Communication System band (PCS). Applications in present-day mobile communication system usually require smaller size RF devices in order to meet the miniaturization Requirements of mobile units [1-5].

The first dual frequency Wilkinson Power Divider was proposed for an operating frequency (f0) and with its first even harmonic (2f0) [6]. In [1], a dual frequency Wilkinson power divider operating at two arbitrary different frequencies has been proposed. Dual band Wilkinson power divider with different schematic structures has been presented in [2, 3, 7, 8].

Defected Ground Structure (DGS) has slow wave effect property and band rejection characteristics which are used for size reduction and harmonic suppression respectively. Recently, the Defected Ground Structure (DGS) has been used in different microwave and millimeter-wave circuits for various applications such as size reduction, harmonic suppression [10] and improving S-parameters [9]. By applying DGS to micro strip line, we can increase the effective impedance of the line which leads to longer electrical length resulting in size reduction of circuit. In this paper, we use a dumbbell DGS unit for miniaturization of the dual-band Wilkinson power divider.

As shown above, 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 for conventional dual band WPD is explained. In section III, DGS implementation for size reduction is explained.

II. DESIGN PROCEDURE

Dual frequency Wilkinson Power Divider is a three port network consisting of one input port and two output ports. Basically, it divides power equally or unequally at two different operating frequencies (f1 and f2) depending on the application using it. The power divider is a symmetric structure, so that its analysis can be done by using even and odd mode analysis to determine the parameters of the dual band power dividers.

\[ l_1 = l_2 = \frac{\pi n}{\beta_1 + \beta_2} \] (I)

\[ Z_2 = \frac{1}{\sqrt{2\alpha_1 + \sqrt{4\alpha_1^2 + 2}}} \] (II)

\[ Z_1 = \frac{Z_0 (Z_2^2 + 1)}{Z_2} \] (III)

\[ \alpha = \left( \tan \left( \beta_1 l_1 \right) \right)^2 \] (IV)

\[ \beta = \frac{2\pi}{\lambda} \] (V)

The above mentioned are the equations used for designing the dual frequency Wilkinson Power Divider [1]. The parameter \( \lambda \) denotes the wavelength and \( n \) is a positive integer. The \( l_1 \) & \( l_2 \) are the lengths of transmission lines. The \( Z_0 \) is the reference impedance and \( Z_1, Z_2 \) are the characteristics impedances of the two different transmission lines. \( \beta_1 \) and \( \beta_2 \) are the constants corresponding to first and second operating frequencies. 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 FR4 with thickness of 1.6 mm, a relative permittivity of 4.3 and a conductor thickness of 0.072mm. The total area is 5.9x4.1 cm². We have used Agilent –ADS 2009 to simulate the dual band Wilkinson Power Divider.

![Fig. 1: A dual-band Wilkinson power divider for f1 = 0.9425GHz and f2 = 1.8425 GHz](image-url)
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The designed dual-band WPD is shown in Fig.1. The parameters S11, S21, and S31 are shown in Fig. 2. As illustrated, our elementary WPD is operating at f1 = 0.9425 GHz and f2 = 1.8425 GHz. It indicates that we have an equally divided and transmitted signal to the output ports at our both operating frequencies. Also S11 shows good performance. We know that at lower operating frequencies, larger area is required for greater values of operating wavelength. By implementing DGS, operating frequencies gets shifted to lower frequencies resulting in the increased electrical length with the same physical size. Hence it shows that slow wave effect property of DGS results in size reduction of the circuit.

III. DGS IMPLEMENTATION

As shown in Fig.4, here we have applied dumb-bell shape DGS to the conventional Dual-band Wilkinson power divider. After applying DGS we found that operating frequencies get shifted to lower frequencies resulting in the increased electrical length. Once position of DGS is decided, we decreased the length of the both transmission lines to get outputs at operating frequencies and we found that total length is reduced by 8 mm as shown in fig.4.

Fig. 2: Simulation result of S-parameters (S11, S21, S31) for the dual frequency Wilkinson power divider

Fig. 3: Simulation result of S-parameters (S23, S22, S33) for the dual frequency Wilkinson power divider

Fig. 4 (a): conventional dual band WPD (b) miniaturized dual band WPD

Fig. 5: Back view of miniaturized dual band WPD

As shown in above fig.5 is the dual band Wilkinson power divider with DGS at its ground plane. Dumb-bell shape DGS is used to shift the frequencies i.e. it has slow wave effect property while rectangular shape is used to improve S-parameter of the dual-band Wilkinson power divider. The dimensions of dumb-bell shaped DGS are A = 1 mm, B = 2.1 mm, and C = D = 4 mm and rectangular shape DGS is 16x5 mm, where A is slot height, B is slot width and C, D are dimensions of dumb-bell.

Fig. 6: Simulation result of S-parameters (S11, S21, S31) for the dual frequency Wilkinson power divider with DGS

Fig. 5: Back view of miniaturized dual band WPD

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IV. CIRCUIT MODELING FOR THE PROPOSED DGS

According to the circuit theory, parallel RLC circuit works as a band-stop filter. By applying the same concept to defected ground structures in micro strip technology, the vertical slot of DGS accumulates charge and increases the effective capacitor of the micro strip line. Two defected areas on both sides and one connecting slot correspond to the equivalently added inductance \( L \) and capacitance \( C \), respectively. Defected ground structure disturbs the surface current distribution in the ground plane.

\[
C = \frac{W_c}{2\pi Z_0 (W_0^2 - W_c^2)} \\
L = \frac{1}{4\pi^2 F_0^2 C} \\
R(W) = \frac{2Z_0}{\sqrt{(1/S_{11}(w))^2 - (2Z_0(wC - 1/wL))^2 - 1}}
\]

For the proposed DGS, equivalent parallel RLC circuit is obtained as shown in the Fig 9.
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V. CONCLUSION
This paper has combined dumb-bell defected ground structure with Dual-band Wilkinson power divider in order to reduce its size and improving s-parameters of it, which previously has been done for single-band WPD.

- The results we have achieved for conventional dual band Wilkinson power divider are as follows. Input reflection coefficient $S_{11}$ is $-34$ dB at 0.9425 GHz and $-35$ dB at 1.8425 GHz. Insertion losses ($S_{21}, S_{31}$) are $-3.293$ dB.

- At both frequencies which shows equal power division. Output reflection coefficient ($S_{22}, S_{33}$) are $-35$ dB at 0.9425 GHz and $-40$ dB at 1.8425 GHz which indicates good matching of the output ports. Isolation ($S_{23}$) between two output ports is $-34.45$ dB at 0.9425 GHz and $-32.3$ dB at 1.8425 GHz which shows that port -2 and ports -3 are isolated properly.

- The results we have achieved for miniaturized dual band Wilkinson power divider are as follows. Input reflection coefficients $S_{11}$ is $-29$ dB at 0.9425 GHz and $-30$ dB at 1.8425 GHz which indicates an average matching at input port.

- Insertion losses ($S_{21}, S_{31}$) are $-3.34$ dB at both frequencies which shows equal power division. Output return losses ($S_{22}, S_{33}$) are $-32$ dB at 0.9425 GHz and $-29$ dB at 1.8425 GHz. Isolation ($S_{23}$) between two output a port is $-30.2$ dB at 0.9425 GHz and $-32.2$ dB at 1.8425 GHz & it needs to be improved for good isolation purpose. By using DGS we have achieved the size reduction of 15.8%.

REFERENCES