A Miniaturized Wideband Wilkinson Power Divider

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Abstract

A miniaturized wideband Wilkinson Power Divider realized using OMMIC ED02AH Technology is presented. Simulation and optimization are accomplished by Advanced Design System (ADS). The final optimization results shows that it has a bandwidth of 76.5% $(8.4 - 18.8GHz)$, 1dB insertion loss and good isolation $(< -12dB)$ between the output ports. The layout of the presented power divider is given, which shows that compacted size $(0.75 \times 0.45mm^2)$ is achieved successfully.

I. Introduction

The power divider is one of the crucial elements in microwave and millimeter-wave systems. Wilkinson power divider is one of the widely used components since it can be designed as arbitrary power division. Even only with regard to the equal-split (3dB) case, there already emerged many works focussed on obtaining wideband responses. Using Chebyshev prototypes and dual-frequency approaches [1–4] are examples that made efforts on wideband improvement of the Wilkinson power divider.

However, the conventional Wilkinson power divider is often made in microstrip or stripline form [5]. Since the nature of the transmission line length decides the final size of the power divider, the conventional Wilkinson power dividers have relative huge size which has long impeded its applications in monolithic microwave integrated circuits (MMICs). Consequently, many efforts have been made to miniaturize the size of a Wilkinson power divider, such as using three-dimensional(3-D) technologies [6], replacing the transmission line sections with lumped passive components [7, 8], lumped-distributed techniques [9], and capacitive loading [10].

In this paper, we propose a novel miniaturized wideband Wilkinson power divider that provides equal power split, good output port isolation, and good return loss at all three ports by using the matured transmission line dual-frequency design theory and the lumped-distributed technologies.

II. Design Method

A. *The original transmission line circuit construction of the Dual-Frequency Wilkinson Power Divider*

A original transmission line schematic diagram of the proposed Wilkinson power divider, which realizes an equal power division at two arbitrary frequencies, is shown in Fig.1 [1]. The input port connects with two symmetrical branches. Each of the branches has two sections of transmission line with the characteristic impedance of Z_1 and Z_2 and the length of l_1 and l_2, respectively.Z_0 is the reference impedance. The output ports are connected with a parallel connection of a resistor

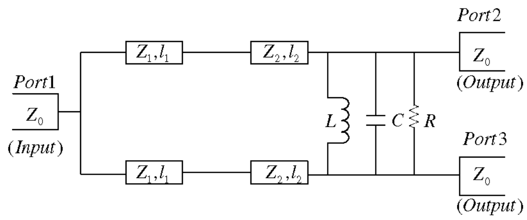

Figure 1: Dual-frequency Wilkinson power divider.

R, an inductor L, and a capacitor C. In order to determine the circuit parameters, paper [1] did detailed even- and odd-mode analysis of this kind of dual-frequency power divider, which operates at two arbitrary frequencies of interest f_1 and $m \cdot f_1$, where m is the frequency ratio. These circuit parameters are listed here:

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

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

$$Z_1 = \frac{2Z_0^2}{Z_2} \tag{3}$$

$$R = 2Z_0 \tag{4}$$

$$C = \frac{\frac{B}{\omega_1} - \frac{A}{\omega_2}}{\frac{2\omega_2}{\omega_1} - \frac{2\omega_1}{\omega_2}} \tag{5}$$

$$L = \frac{\frac{2\omega_2}{\omega_1} - \frac{2\omega_1}{\omega_2}}{B\omega_1 - A\omega_2} \tag{6}$$

where

$$\alpha = (\tan(\beta_1 \cdot l_1))^2 \tag{7}$$

$$\beta = \frac{2\pi}{\lambda} \tag{8}$$

$$p = \tan(\beta_1 \cdot l_1) \tag{9}$$

$$q = \tan(\beta_2 \cdot l_1) \tag{10}$$

$$A = \frac{Z_2 - Z_1 \cdot p^2}{Z_2 \cdot p \cdot (Z_1 + Z_2)} \tag{11}$$

$$B = \frac{Z_2 - Z_1 \cdot q^2}{Z_2 \cdot q \cdot (Z_1 + Z_2)} \tag{12}$$

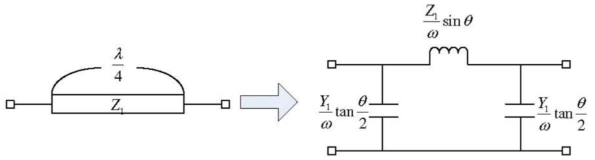

Figure 2: π-type equivalent-circuit representation and equivalent parameters for each quarter-wavelength transformers.

The following important relationship between the positive integer n and frequency ratio m, which is a rational number larger than 1, had also been summarized [1]: with $n = 1$, a dual-frequency Wilkinson power divider operating at f_1 and $m \cdot f_1$, where $1 < m < 3$, can be realized.

B. *The Lumped equivalent π-Network of a Transmission-Line Section*

According to the concept of replacing the transmission line sections with lumped passive components, each quarter-wavelength transformer can be represented to a π-type equivalent circuit. Using even-odd mode analysis, the π-type equivalent-circuit representation is shown in Fig.2 [11].

III. Design Procedure of a Miniaturized Wideband Wilkinson Power Divider

As we mentioned in Section B., we can replacing the transmission line sections with lumped passive components to reduce the circuit size. A conventional Wilkinson power divider operates only at one design frequency f_1. Therefore, the corresponding lumped component equivalent circuit also only operates at the design frequency f_1. In order to improve the bandwidth of the miniaturized power divider, we utilize the theory of the dual-frequency power divider mentioned in Section A. to choose a arbitrary second resonate frequency $f_2 = m \cdot f_1$ to generate a dual-frequency power divider. Then replace the two transmission line sections of the dual-frequency power divider with lumped passive components. Considering the lumped elements circuit do not have a reference impedance, which is a unique characteristic of transmission line, the two LC π-network will merge together and lose each of their resonate frequency. However, we still can image that the assumed second arbitrary resonate frequency f_2 must have some effects on the final bandwidth of the miniaturized Wilkinson power divider.

A. *Calculation of Parameters*

Firstly, we choose the character impedance is $Z_0 = 50\Omega$, the design frequency $f_1 = 15GHz$ and the second resonate frequency $f_2 = 35GHz$. According to Section A., we can calculate the corresponding parameters of the dual-frequency power divider as below:

$$1 < m = \frac{f_2}{f_1} = 2.3 < 3 \tag{13}$$

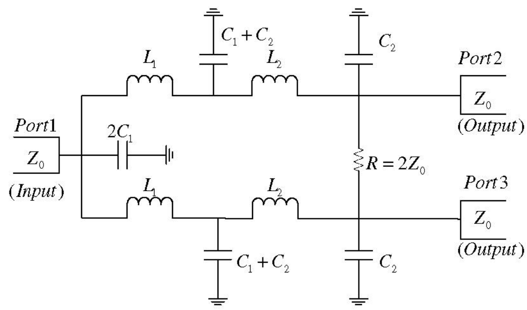

Figure 3: Lumped equivalent circuit for the Wilkinson power divider using π-type equivalent-circuit.

$$l_1 = l_2 = \frac{\pi}{3.3\beta_1} = \frac{\lambda_1}{6.6} = 54.5^\circ \tag{14}$$

$$\alpha = (\tan(\beta_1 \cdot l_1))^2 = (\tan(\frac{\pi}{3.3}))^2 = 1.972 \tag{15}$$

$$Z_2 = Z_0\sqrt{\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + 2}} = 65\Omega \tag{16}$$

$$Z_1 = \frac{2Z_0^2}{Z_2} = 77\Omega \tag{17}$$

The lumped component L and C connected between two output ports in original microstrip line power divider can improve the isolation of the two output ports. However, after replacing the transmission circuit with the lumped components circuit, remaining the lumped component L and C between two output ports will affect the balance of the two branch of the power divider. Furthermore, in order to simplify the lumped elements circuit and minimize the power divider's fabrication size, the inductor L and capacitor C which are connected between the two output ports are removed. Thus, by employing the π-type equivalent circuits (Section B.) of each transmission line section, the equivalent circuit of the power divider can be represented as shown in Fig.3. The equivalent-circuit element value can be derived as follows:

$$L_1 = \frac{Z_1}{\omega_0}\sin\theta \tag{18}$$

$$L_2 = \frac{Z_2}{\omega_0}\sin\theta \tag{19}$$

$$C_1 = \frac{Y_1}{\omega_0}\tan\frac{\theta}{2} \tag{20}$$

$$C_2 = \frac{Y_2}{\omega_0}\tan\frac{\theta}{2} \tag{21}$$

where $\omega_0 = 2\pi f_1$ is the designed angular frequency of the power divider and $\theta = l_1 = l_2$. Table 1 shows out the original calculated equivalent-circuit element values.

B. *Design and Simulation*

The miniaturized Wilkinson power divider was designed by using proposed equivalent circuit with OMMIC ED02AH

Table 1: The original calculated equivalent-circuit element values

$R(\Omega)$	$L_1(nH)$	$L_2(nH)$	$C_1(pF)$	$C_2(pF)$
100	0.665	0.5615	0.071	0.084

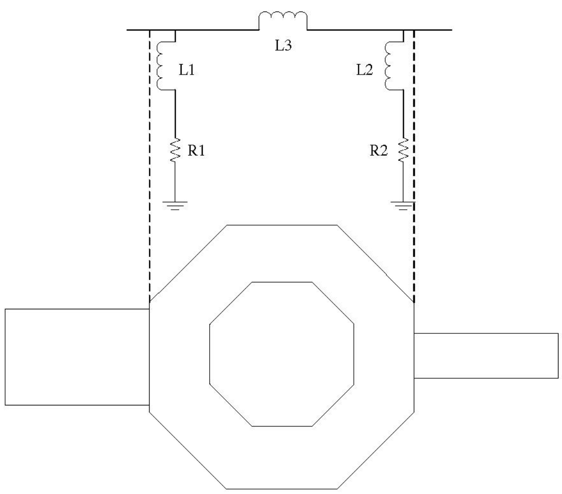

Figure 4: The OMMIC ED02AH model for the via hole.

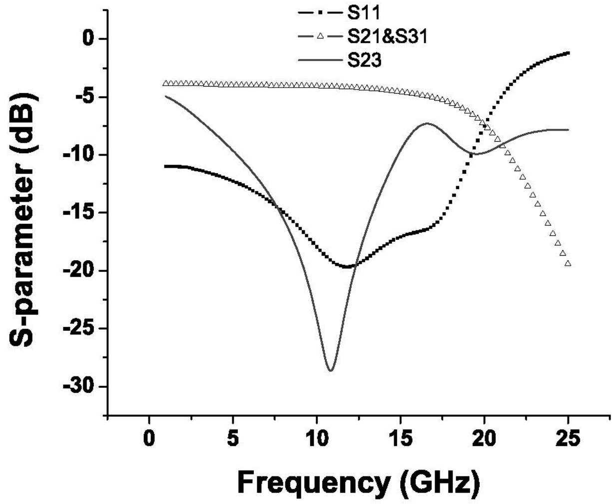

Figure 5: Simulated S-parameter of the Wilkison power divider with the original calculated equivalent-circuit element values.

technology and simulated with ADS. The OMMICED02AH technology model the behavior of the via hole accurately through the proposed model for the via hole with one access, or with two accesses at opposite entrance points, as shown in Fig.4. In this via hole's model, the inductor $L1 = L2 = 22pH$, $L3 = 60pH$, and $R1 = R2 = 0.4\Omega$. Fig.5 shows the simulation results of the designed power divider based on the equivalent circuit with the original calculated equivalent-circuit element values.

IV. Optimization Results and Layout

As mentioned before, an arbitrary frequency f_2 is selected randomly to design the duel-frequency transmission line power divider. However, with replacing the transmission line with the LC components, the proposed lumped circuit will lose the original selected resonate frequency f_2. The performance of the lumped elements power divider cannot be expected. Moreover, the parasites of inductors, via holes and inter connectors are considered in the provided OMMIC ED02AH models. Therefore, optimization is needed to improve the performance of the proposed power divider. Fig.6 shows the optimized simulation results of the final proposed wideband Wilkinson power divider.

Table 2: The optimizated LC values

$R(\Omega)$	$L_1(nH)$	$L_2(nH)$	$C_1(pF)$	$C_2(pF)$
100	0.6382	0.3248	0.050	0.030

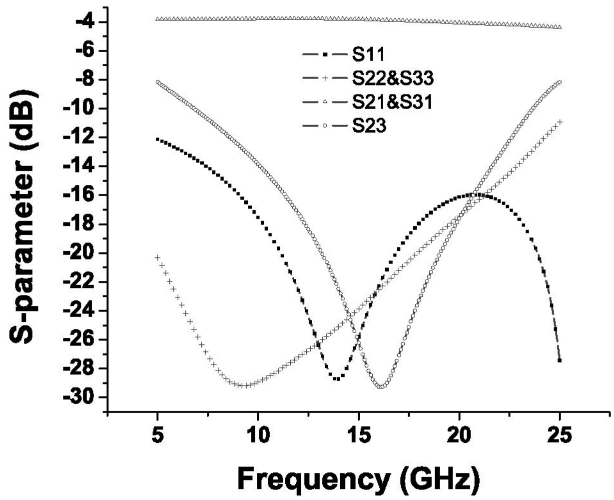

Figure 6: Optimized S-parameter of the Wilkison power divider .

From the S-parameters, the bandwidth, defined as the frequency range where $|S_{11}| < -15dB$, is 76.5% (from 8.4 to 18.8 GHz). Within this bandwidth, insertion loss ($|S_{21}| = |S_{31}|$) maintains lower than 1 dB, while the isolation, characterized by $|S_{23}|$, is better than 12 dB.
Fig.7 shows the final layout of the power divider. The total chip area is $1.13 \times 0.98mm^2$ including the pad frame, where the active area occupy $0.75 \times 0.45mm^2$.

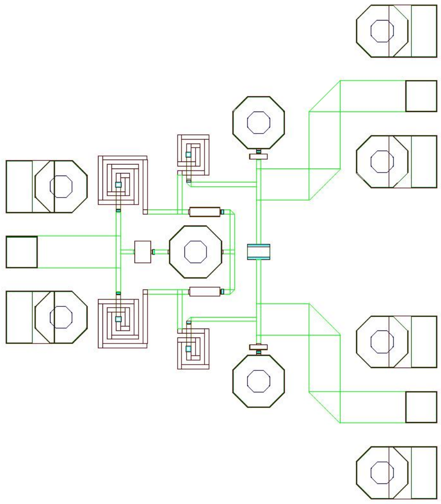

Figure 7: The final layout of the miniaturized broadband Wilkison power divider .

V. Conclusion

In this paper, we utilized the matured transmission line dual-frequency design theory and the lumped-distributed technologies to present a new miniaturized wideband Wilkinson power divider. The proposed Wilkinson power divider provides a wideband equal-split output signal as well as excellent return loss and good isolation. Furthermore, compact active size ($0.75 \times 0.45mm^2$) is achieved successfully, which is more suitable for applications in monolithic microwave integrated circuits (MMICs).

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