Simple Miniaturized Wilkinson Power Divider Using A Compact Stub Structure

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Abstract— **The paper presents a study on the miniaturization of microwave power dividers/ combiners. The authors propose a modified two-way Wilkinson power divider with dimensions of 33x24mm, twice reduced compared to the standard structure (65x24mm). This new structure has been designed based on an "artificial transmission line" consisting of a microstrip line and two shunt capacitors at its edges where the capacitors are replaced by two open-ended stubs located inside the circuit loop and do not take any additional space. The power divider has good performance at the designed frequency 900 MHz and its bandwidth of over 1 GHz is sufficient for various applications. The simulation has been performed in both Agilent ADS/ Momentum and CST Microwave Studio and good agreement of the results obtained in these design tools was obtained. Two prototypes have been fabricated and tested, and the measurement results fit well with the simulation. This approach can be applied to design other microwave circuits where quarter-wavelength transmission lines are required, and the modified Wilkinson power divider can be used for various applications such as measurement systems or in antenna array feeding circuits.**

Keywords—power divider/combiner; Wilkinson power divider; microwave integrated circuit; antenna array feeding circuit

I. INTRODUCTION

Wilkinson power dividers/combiners are widely used in microwave power amplifiers, mixers or feeding circuits for antenna arrays thanks to their great balanced properties. However, their big size with quarter-wavelength branches is one of disadvantages that limit the use of those circuits.

There have been many publications on Wilkinson power dividers with various purposes, including size reduction and/or arbitrary power division. For miniaturization, the authors proposed various methods, such as using high-low impedance resonator cells [1], small phase delay method [2], serial inductors [3], series lumped RLC circuits [4], periodically loaded slow wave structure [5], defected ground structure [6], electromagnetic bandgap (EBG) cells [7]. Most of research papers present good performance with high rate of size reduction. However, many proposed circuits are complicated with external mounted lumped components or with etching on both sides of the circuit that is sometimes inconvenient to fabricate.

In this paper, a simple modified Wilkinson power divider using a compact stub structure with the dimensions of 50% reduced is proposed. The following Sections II and III of the paper will present theoretical background for the design, propose a designed circuit at 900 MHz, then compare the obtained theoretical and experimental results. Finally, the conclusions are given in section IV.

II. MODIFIED WILKINSON POWER DIVIDER

In the basic structure of a Wilkinson power divider, two symmetrical quarter-wavelength branches provide matching conditions at all its ports (Fig. 1(a)) causing big dimensions of the integrated circuits using it. If those branches are replaced by some other structures with the same characteristics, we can obtain a more compact Wilkinson power divider. In [8], the authors used an "artificial" transmission line structure to replace half-wavelength transmission lines in branch-line and rat-race hybrids.

Fig. 1(b) shows the modified two-way Wilkinson circuit where each quarter-wavelength branch is replaced by an "artificial" transmission line structure, consisting of a shorter line with two shunt capacitors at its edges. In order to use this approach, it is needed to determine the values of the characteristic impedance (R_a), the electrical length θ of the transmission line branches and the capacitance C so that this new circuit is equivalent to the conventional Wilkinson power divider.

Let us consider a half-circuit of the odd mode presented in Fig. 2(a). In order to have matching at the ports 2 (and 3, consequently), the following condition must be taken in place:

$$Y_{in2}^{odd} = G_0$$

Where G_0 is the characteristic conductance at the ports.

$$Y_{in2}^{odd} = G_0 + j\omega C + \frac{1}{Z_{in2}^{'}},\ Z_{in2}^{'} = jR_a \tan\theta$$

$$Y_{in2}^{odd} = G_0 \Rightarrow j\omega C + \frac{1}{Z_{in2}^{'}} = 0 \Rightarrow \omega C = G_a \cot\theta \,,$$

i.e. $\omega C = \dfrac{\cot\theta}{R_a}$ (1)

Fig. 2(b) shows the even mode circuit, where the symbol Z_L represents the load at port 1,

$$Z_L = 2R_0$$

We have:

$$Y_{in2}^{''} = G_a \frac{(Y_L + j\omega C) + jG_a \tan\theta}{G_a + j(Y_L + j\omega C)\tan\theta}$$

$$= G_a \frac{(Y_L + jG_a \cot\theta) + jG_a \tan\theta}{G_a + j(Y_L + jG_a \cot\theta)\tan\theta} = \frac{\left(\frac{G_a}{\sin\theta}\right)^2}{Y_L} - jG_a \cot\theta$$

$$\Rightarrow Y_{in2}^{even} = Y_{in2}^{''} + j\omega C = \frac{\left(\frac{G_a}{\sin\theta}\right)^2}{Y_L}$$

In order to match the port in the even mode, we must have the following:

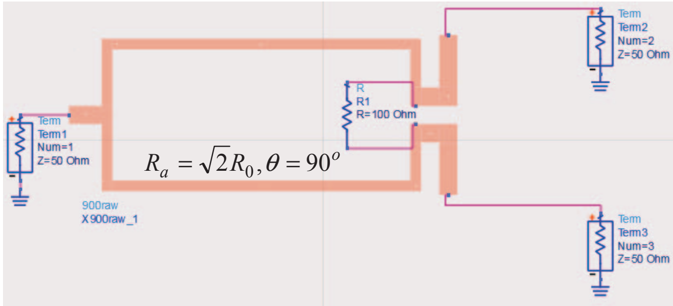
$$\frac{\left(\frac{G_a}{\sin\theta}\right)^2}{Y_L} = \frac{G_0^2}{Y_L} \Rightarrow \frac{G_a}{\sin\theta} = G_0$$

As a result, we obtain $R_a = \dfrac{R_0}{\sin\theta}$ (2)

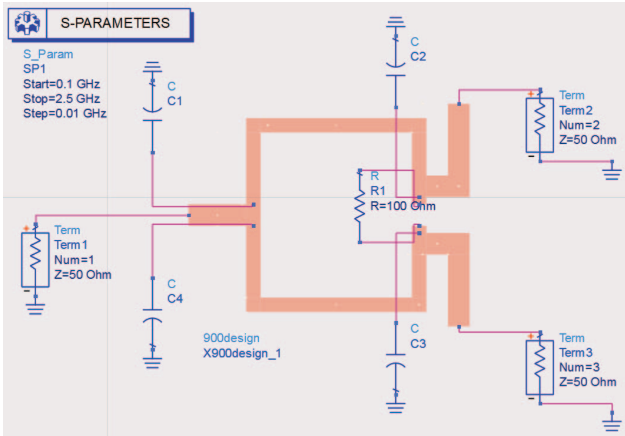
The formula (1) and (2) are used to determine the equivalent transmission line and the necessary capacitance C for the modified Wilkinson power divider. With a good choice of R_a, θ and C we can reduce the total dimensions by about 40%.

However, this method is not always good due to tolerance of the mounted capacitors that can cause huge inaccuracy especially at high frequency. In order to avoid this, each capacitor can be replaced by a shunt microstrip stub as shown in the ADS schematic model in Fig. 3. To realize this approach, a special stub structure is proposed in Fig. 4 where all stubs are located inside the circuit loop so that they do not take additional places. As a result, the dimension of the modified Wilkinson power divider is reduced by 50%.

$$R_a = \sqrt{2}R_0, \theta = 90^o$$

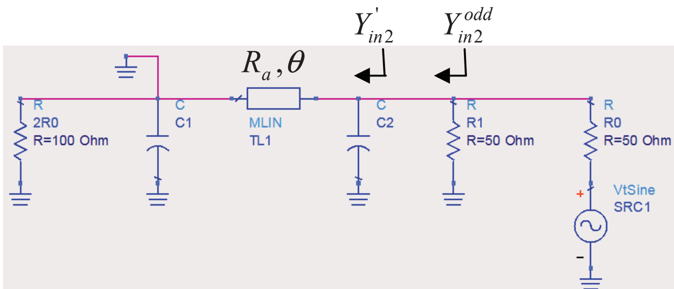


(a)

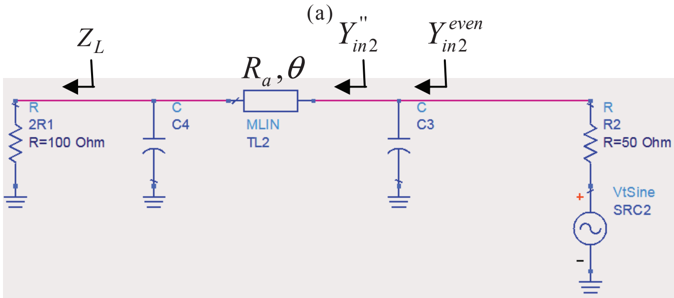


(b)

Figure 1 ADS model of (a) the conventional and (b) modified Wilkinson power dividers



(a)



(b)

Figure 2 The modified Wilkinson power divider circuit analysis in (a) Odd mode and (b) Even mode

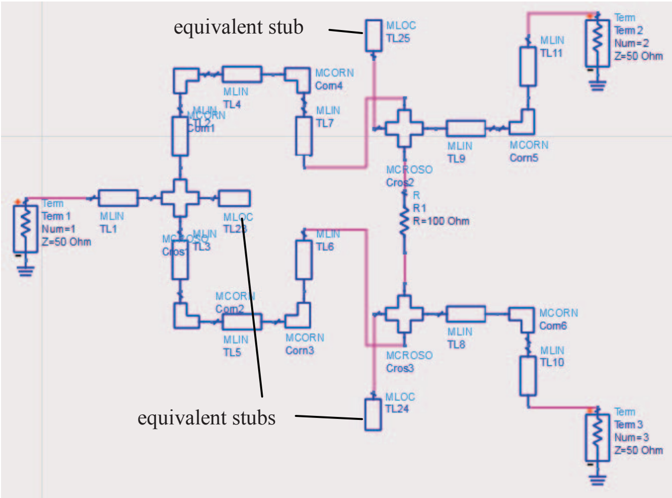


Figure 3 ADS schematic model of the Wilkinson Power Divider using stubs

III. Results and Discussion

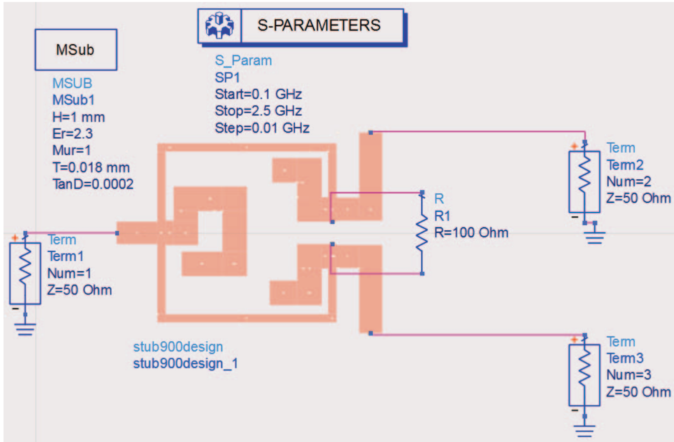
The circuit has been designed at 900 MHz on Teflon substrate ($\varepsilon_r = 2.3, \tan\delta = 0.0002$) with 1mm thickness. In order to verify the accuracy of the design, the simulation has been carried out on both Agilent ADS/Momentum and CST Microwave Studio (Fig. 4) and found good agreement between two simulations. The dimension of the modified structure is 33x24mm, twice reduced compared to the standard Wilkinson power divider (65x24mm) at the same frequency.

Two prototypes have been fabricated for each conventional and modified structure (Fig. 5) and measured with HP 8510C Vector Network Analyzer at Nakano Laboratory, Hosei University, Tokyo, Japan. It was found out, that the measurement results are nearly identical for each pair of prototypes that confirms good quality of the fabrication process. Fig. 6 shows the good matching at 900 MHz at all ports of the modified structure in comparison with the conventional Wilkinson power divider, where the simulated |S11| and |S22|, |S33| of the proposed power divider are -59 dB and -23.5 dB, -23.5 dB, and their measured values are -27 dB, -27.5 dB and -27.5 dB, respectively. The matching bandwidth is over 1 GHz that is acceptable for various applications.

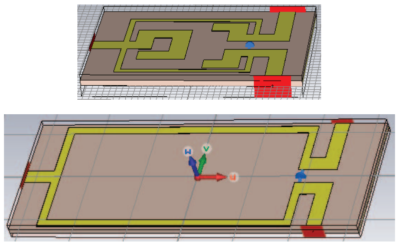
The measured transmission coefficients |S21| and |S31| fit well with the simulated and have the value of -3.05 dB at the designed frequency (Fig. 7). Fig. 8 shows the excellent isolation level between two outputs 2 and 3 of both conventional and modified circuits, where for the modified one the simulated |S32| = -42 dB and the measured of -29 dB at 900 MHz, nearly as good as the conventional circuit. It is noted from both simulation and measurement, that even though the structure is not quite geometrically symmetric, but |S22| and |S33| have the same values and the signals at two outputs 2 and 3 are identical. Table 1 summarizes all simulation and measurement results for the proposed modified Wilkinson power divider circuit. There are some disagreement between simulation and measurement that can be caused by imperfection of the cables used for the measurement. However, the overall performance is good, i. e. this circuit works well at the design frequency over a sufficient bandwidth and can be used for many applications.

TABLE I. Simulation and Measurement Results

	Matching		Transmission	Isolation
	|S11|, dB	|S22|, |S33|, dB	|S21|, |S31|, dB	|S32|, dB
Simulation	-59	-23.5	-3.05	-42
Measurement	-27	-27.5	-3.05	-29



(a)



(b)

Figure 4 (a) ADS and (b) CST 3D models of the modified Wilkinson power divider using a special stub structure in comparison with the conventional circuit

IV. Conclusions

In this paper, we proposed a modified two-way microstrip Wilkinson power divider with the total dimensions reduced by 50% compared with the conventional circuit. The circuit has simple microstrip structure, is easy to fabricate and has good performance as of the standard Wilkinson power divider at the designed frequency 900 MHz regardless its imperfect symmetry. This approach can be applied to design other microwave circuits where quarter-wavelength transmission lines are required, and the modified Wilkinson power divider can be used for various applications such as measurement systems or in antenna array feeding circuits.

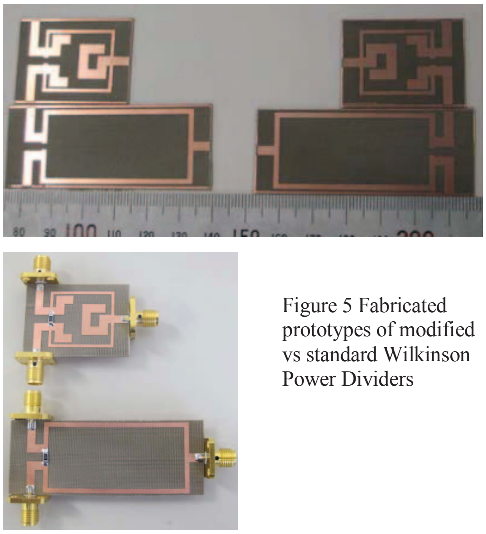


Figure 5 Fabricated prototypes of modified vs standard Wilkinson Power Dividers

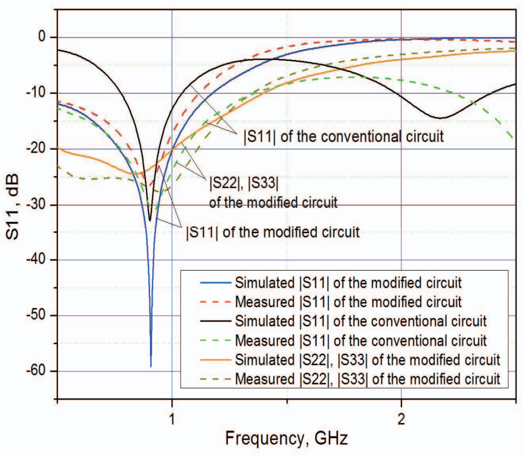


Figure 6 Matching properties of the conventional and modified structures

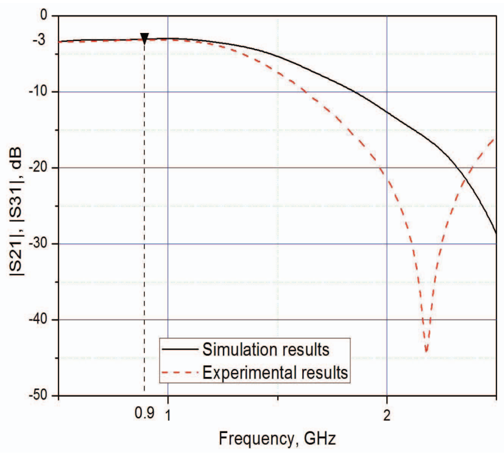


Figure 7 Transmission characteristic of the modified structure

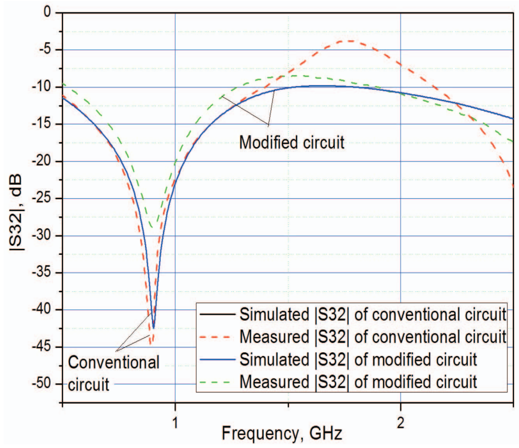


Figure 8 Isolation properties of the conventional and modified structures

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