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A Dual Band Four Ports Wilkinson Power Divider Design

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Abstract **—In the present paper, a dual band four-way Wilkinson power divider (WPD) using a genetic algorithm (GA) optimization is designed and simulated using ADS Momentum simulator. The proposed power divider is developed to support dual bands of WLAN applications. The present power divider is formed by many transmission lines sections. The transmission lines are printed on FR4 (Flame Resistant 4) substrate of dielectric constant ε_r of3.4 with loss tangent of 0.0023.The proposed circuit exhibits good characteristics at WLAN frequencies (2.45GHz & 5.8 GHZ) in terms of return loss and isolation.**

Keywords—Wilkinson power divider; WLAN frequencies; ADS simulator

I. INTRODUCTION

Modern trends in the deployment of wireless communications services (LTE, 5G) require versatile radio frequency (RF) transmitters / receivers [1]. Each wireless communication system includes passive and active microwave circuits such as: Couplers, filters and power dividers.

Power dividers are among the most common passive circuits in RF and microwave applications. These dividers are widely used in antenna arrays, balanced amplifiers, mixers, frequency multipliers. In particular, these dividers are used to provide power to an antenna array; a path must be connected using one or more power dividers (Butler matrix) which allow doing a junction between a single-way entry with the output of multiple ways.

Power dividers have been developed to support multiband and broadband services [2, 3]. The constraints imposed on physical size have become the main concern of the developers; the answer to these design priorities has been to focus a great deal of research on the production of small-sized advanced power dividers [4-7].

The most useful dividers in wireless communications systems are: the Wilkinson Power Divider (WPD) and the GYSEL Power Divider (GPD) because of their low insertion losses on its matchedand isolated ports. Although, the conventional Wilkinson divider (WPD) has a simple structure, it performs well, but with limited bandwidth (isolation).

The main objective of this work is to design a dual band power divider with four output ports while keeping thedifferent performances cited in the analytical study of the WPD divider [8].The rest of the paper is organized as follows: section 2 present brief description of Wilkinson power divider. Section 3 presents the design and optimization of the proposed power divider. Section 4 presents the simulation results and discussions. Finally, main conclusions are drawn in section 5.

II. WILKINSON POWER DIVIDER

The Wilkinson Power Divider (WPD) is a lossy three-port network; it is assumed that all ports are matched, with good isolation between the two output ports. It comprises two transmission lines whose length is equal to λ / 4, where λ is the wavelength. Each line has a characteristic impedance of $\sqrt{2}Z_0$ and an insulation resistance R = $2Z_0$.The scheme of a WPD with two identical power outputs is shown in Fig 1.

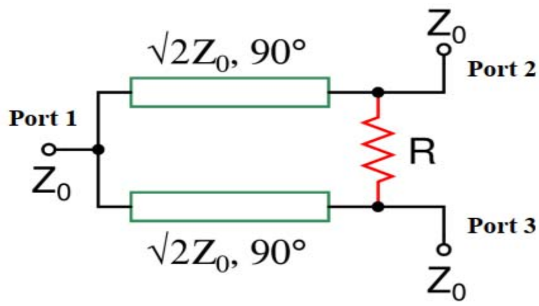

Fig. 1.WILKINSON divider with two equal power way.

The WPD can be easily analyzed using the odd-even mode procedure [9]. The WPD illustrated previously in Figure 1 is redrawn symmetrically in standardized form inFig 2. In the normalized form, eachimpedance is divided by the characteristic impedance of the input line Z_0.

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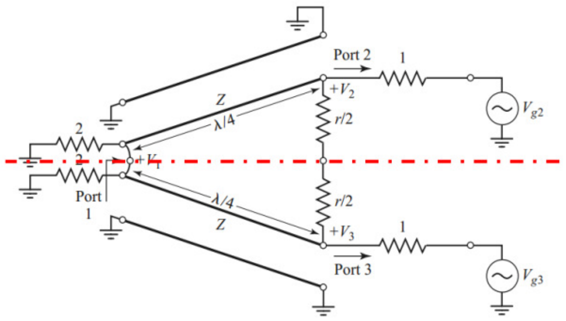

Fig. 2. The symmetrical and standardized form of the WPD.

In the case of the even mode, the same voltage source is applied to ports 2 and 3 ($V_{g2} = V_{g3} = 2V_0$), therefore the circuit is simplified as shown in Fig 3.

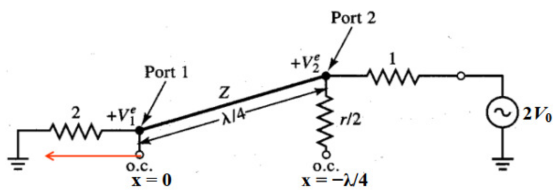

Fig.3.The equivalent circuit of the WPD in even mode.

On the other hand, in the odd mode, $V_{g2} = -V_{g3} = 2V_0$ and, consequently, this mode has the effect of introducing a virtual mass at port 1, and at the center of the impedance 2Z as shown in Fig 4.

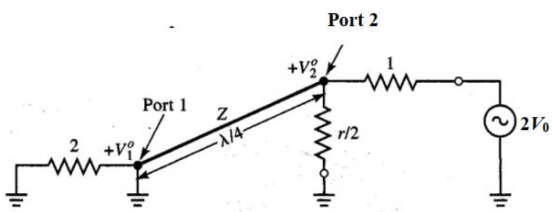

Fig. 4. The equivalent circuit of the WPD in odd mode.

In the even-mode half-circuit as shown in Fig3, it is obvious that the isolation (balance) resistor has no effect in this mode; because it is equivalent to an open circuit. Therefore, the input impedance at port 2 is given by:

$$Z^e_{in} = \frac{Z^2}{2} \quad (1)$$

According to the x-axis shown in Fig4, the voltage on the transmission line can be expressed as follows:

$$V(x) = V^+(e^{-j\beta x} + \Gamma e^{j\beta x}) \quad (2.a)$$

$$V^e_2 = jV^+(1-\Gamma) = V_0 \quad (2.b)$$

This gives

$$V^e_1 = V^+(1+\Gamma) = jV_0\frac{\Gamma+1}{\Gamma-1} \quad (2.c)$$

Since $\Gamma = \frac{2-\sqrt{2}}{2+\sqrt{2}}$ therefore

$$V_e^1 = -j\sqrt{2}\, V_0 \quad (2.d)$$

For odd-mode excitation, since port 1 is short-circuited and the line has a length of λ / 4, the input impedance of the line at port 2 is infinite. To make an adaptation at port 2, r = 2. So $V^o_1 = 0$ and $V^0_2 = V_o$

Finally, as indicated previously, the equivalent circuit constituted of two quarter-wavelength lines connected in parallel to the input port, and charged with a unitary resistance (the isolation resistance has no effect due to the absence of a potential difference between its terminals), the normalized input impedance is equal to 1.

After this analysis, we can conclude that:

$$S_{11} = S_{22} = S_{33} = S_{23} = S_{32} = 0 \quad (3)$$

$$S_{12} = S_{21} = S_{13} = S_{31} = S_{31} = -j/\sqrt{2} \quad (4)$$

$$\bar{S} = \begin{bmatrix} 0 & -j/\sqrt{2} & -j/\sqrt{2} \\ -j/\sqrt{2} & 0 & 0 \\ -j/\sqrt{2} & 0 & 0 \end{bmatrix} \quad (5)$$

III. DESIGN OF A POWER DIVIDER FOR WLAN NETWORK APPLICATIONS

In this section, power dividers are designed for wireless local area network (WLAN) applications. Our goal is to design a Wilkinson power divider with four output ports that can be integrated into dual-band systems (WLAN 1: 2.45 GHz and WLAN 2: 5.8 GHz). To achieve our goal, we must optimize the different parameters of the power divider. Optimization can be done using the integrated stochastic methods in the SimulatorADSMomentum. Among these stochastic methods, one can cite genetic algorithms (GA), particle swarm optimization (PSO), and others.

A. WLAN technology

WLAN technology uses OFDM as a multiple access technique (except standard 11b). The maximum distance for communication is 100 meters. WLAN technology communicates in the ISM bands (2.4 GHz and 5 GHz), available all over the world. It is particularly optimized for IP and Ethernet technologies, and perfectly adapted to wireless Internet access [10].

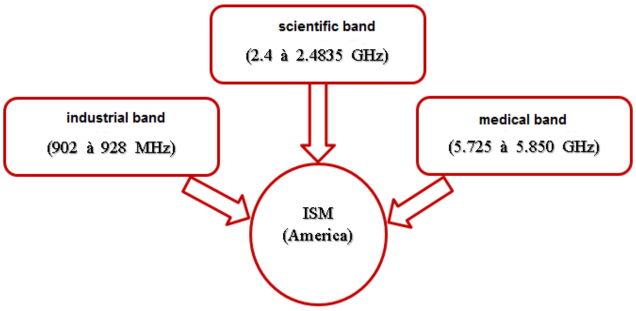

Fig. 5. ISM radio bands defined by FCC.

B. Optimization in the ADS Simulator

In the case of power divider, the optimization under ADS consists of varying one or more parameters of this one, in order to reach a goal; such as the desired operating frequency. The reflection coefficient S_{11} must be under -10 dB in a precise frequency band. The optimization methods include stochastic methods such as genetic algorithms, the particular swarm optimization (PSO) and other analytics such as Newton's method [11].

C. Genetic Algorithm (GA)

GA is an artificial intelligence method simulating natural evolution, based on Darwinian's theory, which uses three main operators of selection, crossover and mutation to produce individuals with better fitness. Genetic operators are the stochastic transition rules applied to each chromosome during each generation procedure to generate a new improved population from the previous one.

Genetic algorithms have many advantages over conventional optimization methods [12]:

- They optimize the real and binary variables.
- They do not require the calculation of the derivatives of a cost function (semi-random).
- They are able to get a global minimum without getting trapped in a local minimum.
- They can lead to a list of solutions

Their major disadvantage lies in the convergence time which is very slow.

IV.GEOMETRY OF THE PROPOSED DIVIDER

The proposed power divider has a structure of an input port and four output ports.This one must be operational on both 2.4GHz and 5GHz WLAN bands. The schematic circuit of the designed power divider is shown in Fig 6.

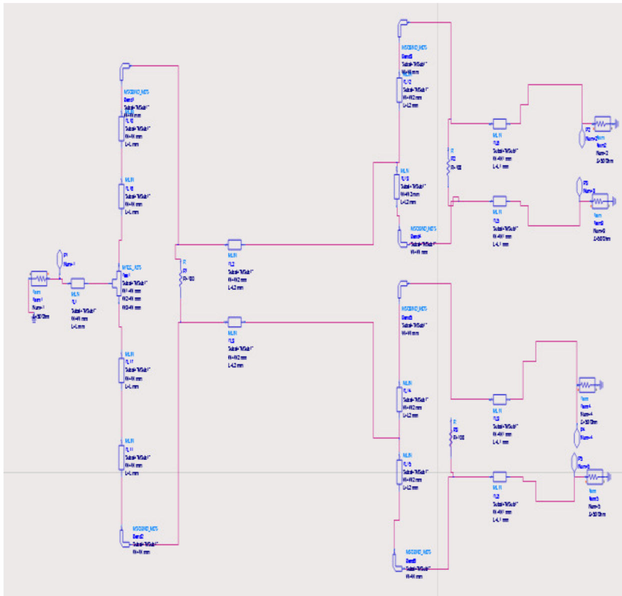

Fig. 6. Schematic circuit of the proposed four-port dual-band power divider using ADS.

The printed circuit of the previous diagram is shown in the Fig 7.

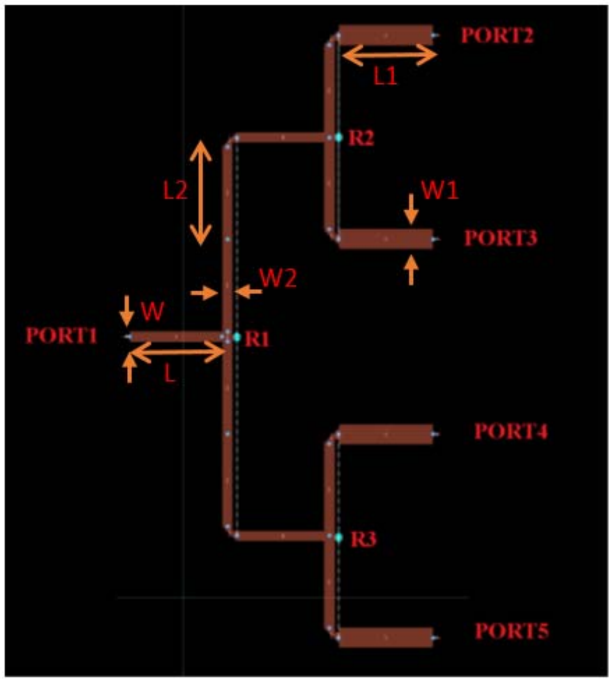

Fig. 7. The layout circuit of the proposed divider.

V.RESULTS AND DISCUSSION

Before starting the optimization process, the different objectives have to be defined, as in Fig 8.

Fig. 8. Setting goals on ADS.

As shown in Fig 8, the type of optimization uses the gradientand the maximum number of iterations is fixed by 50. The goal we want to reach is theoptimization ofthe coefficients $S_{11}$and S_{12}.

The first objective: S_{11} must be less than or equal to -10dB in the following two frequency bands: [1.5 GHz-3GHz] and [4.5GHz-6GHz]. This objective can be expressed by:

$$|S_{11}| \leq -10\ dB \text{for} 1.5\ GHz \leq f \leq 3 GHz \text{et } 4.5\ GHz \leq f \leq 6 GHz$$

The second objective: S_{12} must be greater than or equal to -10dB in the following two frequency bands: [2 GHz-3GHz] and [5GHz-6GHz]. This objective can be expressed by:

$$|S_{12}| \geq -10\ dB \text{for} 2\ GHz \leq f \leq 3 GHz \text{et } 5\ GHz \leq f \leq 6 GHz$$

The obtained results are in the form of the vectors X_f= [L W] for each iteration, where the number of iterations reached is 4, in spite of having fixed the maximum number by 50 (see Table 1).

These vectors obtained during this optimization, as well as the final result, do not represent the optimal solution, but it is sufficient. To find an optimal combination between these parameters (L, W), a classical optimization method must be used.

When running the simulation, ADS gives an optimal structure. Automatically, the obtained design parameters will be applied to the fine model.

The following figures show the frequency responses of the different S parameters in the 1GHz - 6GHz range, for each iteration.

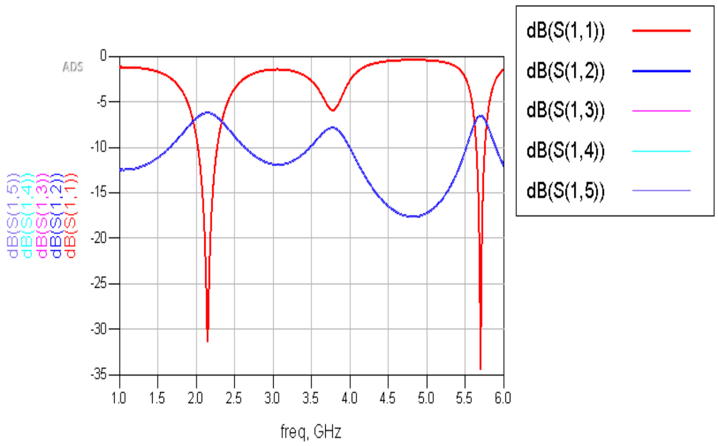

Fig. 9. The responses of the different distribution parameters for the initial vector.

TABLE 1. DIFFERENT DIMENSIONS OF DUAL- BAND POWER DIVIDER SHOWN FOR EACH ITERATION.

Dimensions (mm) / Itération	L	W	L1	W1	L2	W2
Initialisation	3.10186	0.152176	1.19182	0.116544	1.8656	0.1037
1st iteration	3.05926	0.132005	1.19182	0.106234	1.8656	0.9333
2nd iteration	2.91990	0.132005	1.18333	0.800063	1.8656	0.8810
3rd iteration	2.52003	0.132005	1.17057	0.800063	1.8656	0.7339
4th iteration	1.90233	0.132005	1.18333	0.800111	1.8777	0.7003

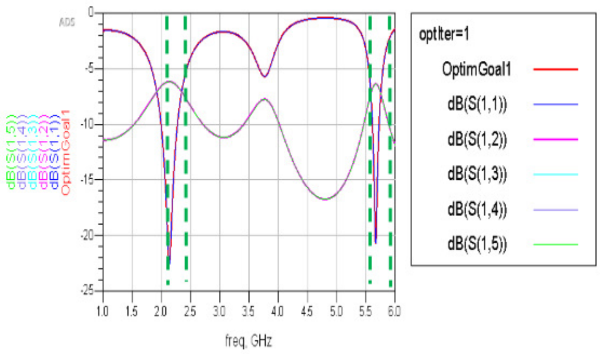

Fig. 10. The responses of the different distribution parameters for the optimal vector after the 1st iteration.

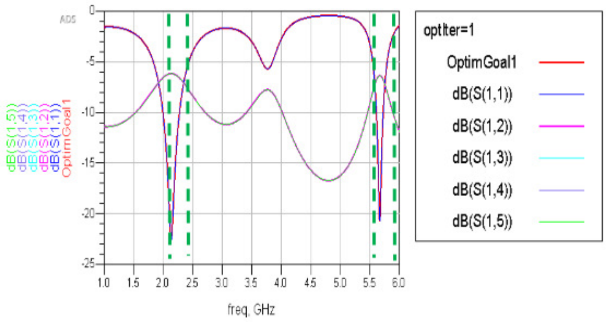

Fig.11. The responses of the different distribution parameters for the optimal vector after the 2nd iteration.

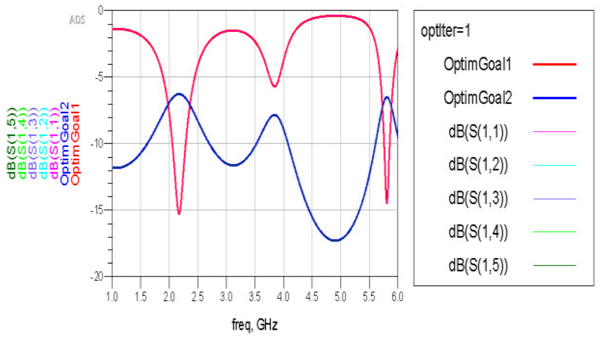

Fig.12. The Responses Of The Different Distribution Parameters For The Optimal Vector After The 3rd Iteration.

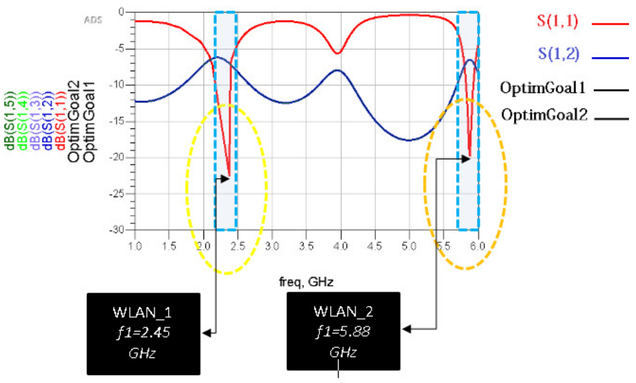

Fig. 13. The responses of the different distribution parameters for the optimal vector after the 1st iteration.

As we have already seen for the different iterations, the objective is reached sufficiently to have a power divider operational on both WLAN bands (1 & 2). We can see, in Fig 9 that the divider operates on the two frequency bands[1.5GHz-3GHz] and [4.5GHz-6GHz]. These two bands cover both scientific and medical WLAN services.

CONCLUSION

In this work, we presented the design of a dual-band power divider with four output ports using the ADS momentum V.2019 simulator. Our goal was to vary the physical dimensions of the proposed power divider until a dual-band WPD dedicated to WLAN 1 & 2 applications is obtained. To achieve this goal, an optimization was done using the simulator ADS Momentum (f_1 = 2.45 GHz and f_2 = 5.8 GHz). Very satisfactory results were obtained.

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