Parametric Study and Optimization of a Dual-BandFour Port Wilkinson Power Divider

Elhadi KENANE , Messaoud GARAH and Fadila BENMEDDOUR

***Abstract* —Among the most used power dividers in the field of telecommunications (antenna networks, mobile networks, radar system, satellite communications,military applications and even missile guidance) we can mention the Wilkinson power divider.In the present paper, a dual band Wilkinson power divider with four ways will be designed.**

In order to investigate the relationship between the physical dimensions of the Wilkinson power divide rwith its characteristics in terms of operational frequency and bandwidth, a parametric study of a Wilkinson power divider will be presented.To design the dual band four-way Wilkinson power divider (WPD), ADS Momentum simulator is used. The simulator uses a genetic algorithm (GA) algorithm to optimize the structure of the proposed WPD.The proposed power divider is developed to achieve dual bands requirements of WLAN applications. To obtain these frequency specifications in the proposed WPD, many transmission lines sections are added. 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.

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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 matched and 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 the different 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 3present a parametric study of this one. Section 4 presents the design and optimization of the proposed power divider. Section 5 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.

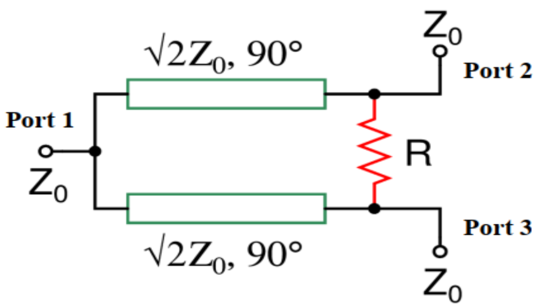

Fig. 1.WILKINSON divider with two equal power way.

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 forminFig2. In the normalized form, eachimpedance is divided by the characteristic impedance of the input line Z_0.

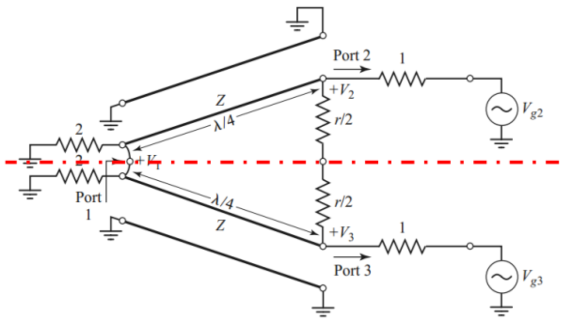

Fig. 2. The symmetrical and standardized form of the WPD.

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.

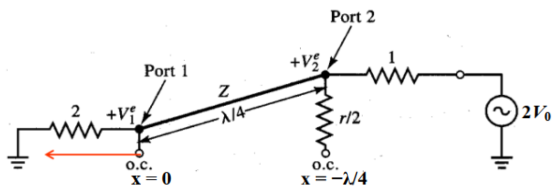

Fig.3.The equivalent circuit of the WPD in even mode.

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.

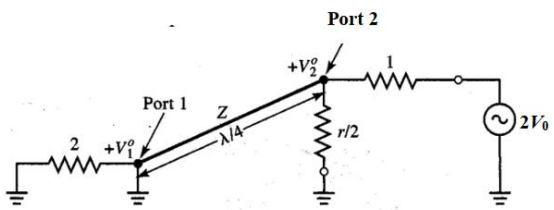

Fig. 4. The equivalent circuit of the WPD in odd mode.

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 $V^o_2 = V_o$

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 Simulator ADS Momentum. 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].

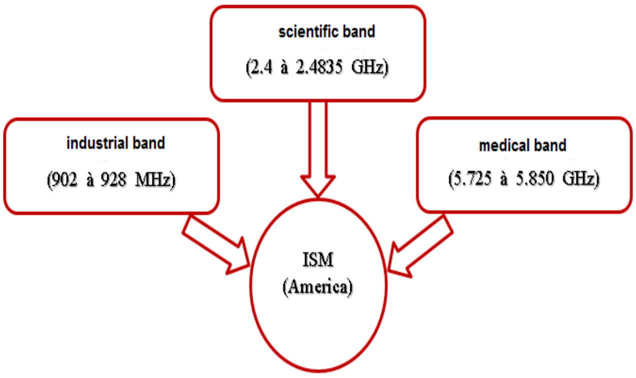

Fig. 24. ISM radio bands defined by FCC.

B. *Optimization in the ADS Simulator*

In the case of power divider, the optimization under ADS consists of varying one or more parameters of the simulated power divider, 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. PARAMETRIC STUDY OF A WILKINSON DIVIDER (WPD)

IV.1 *The Proposed WPD*

To do our parametric study, the proposed WPD is chosen to be as shown in Fig. 5.

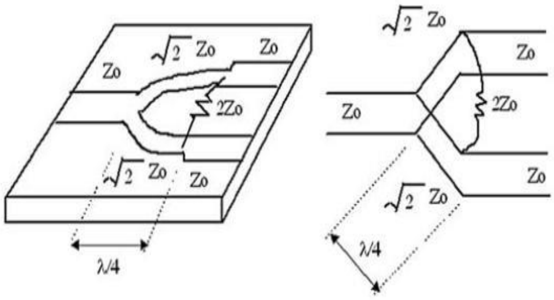

Fig. 5. 2-port power divider topology

Using the ADS Momentum simulator, the electronic diagram of a WPD was created Fig 6.

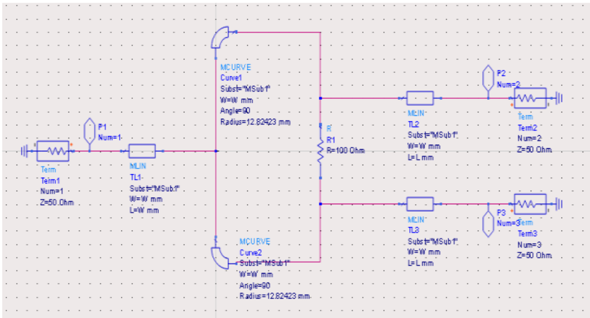

Fig.6.A WPD module using ADS.

The different dimensions of the designed power divider are given in the following table

TABLE 1. THE DIMENSIONS OF A POWER DIVIDER (WPD).

Power divider	Settings	Values (mm)
WPD	L1=L2= L3	7.50
	W1 = W2 = W3	1.4023

The substrate used is of the FR4 (Flame Resistant 4) type with a relative permittivity εr = 4.3. The height of the substrate h = 1.6 mm, the angle of loss tg (α) = 0.0023 and the metal is copper with a thickness T = 35 µm as shown in Fig. 7.

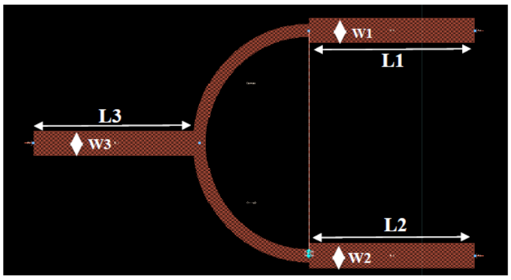

Fig .7. The printed diagram of the WPD generated by the ADS.

The simulation of the proposed WPD will be done for two examples. The first example concerns a substrate of a relative permittivity ε_r of 3.6, while the second one uses a substrate with a relative permittivity ε_r of 4.3.

A. *First example (ε_r = 3.6)*

The Circuit is mounted on FR4 dielectric substrate of a relative permittivity ε_r = 3.6, a constant thickness of 1.6 mm, and a loss angle tg (α) = 0 .0013. The thickness of the copper is T=35um. The evolution of the reflection coefficient S11 is illustrated for the different possible cases. We will vary a single parameter (length Li) where the other parameters are fixed like those tabulated in Table 1.

1) *Effect of the variation of the length L1*

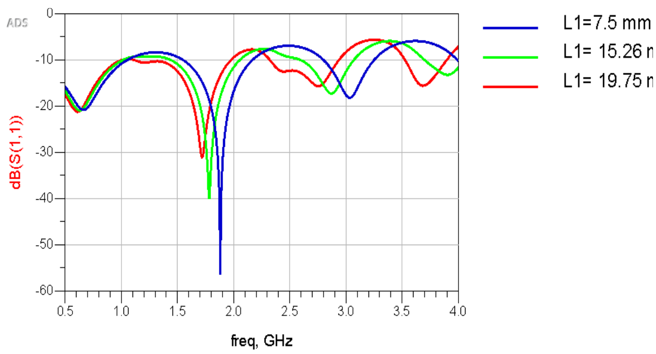

Fig. 8. Evolution of Wilkinson's coefficient S11 with a substrate of εr = 3.6 for different values of L1

2) *Effect of the variation of the length L2*

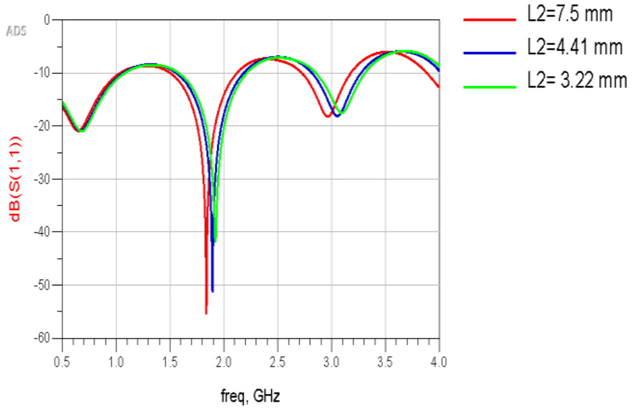

Fig. 9. Evolution of Wilkinson's coefficient S11 with a substrate of εr = 3.6 for different values of L2

3) *Effect of the variation of the length L3*

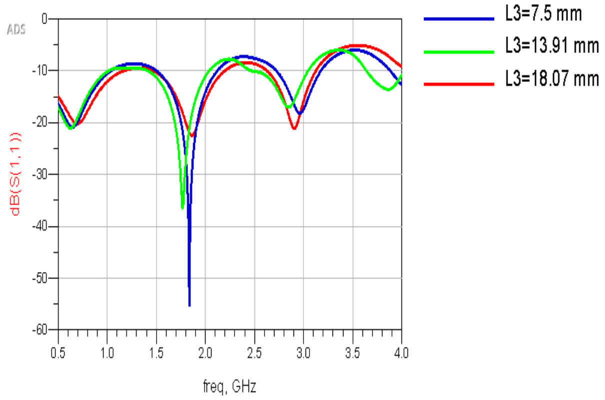

Fig. 10. Evolution of Wilkinson's coefficient S11 with a substrate of ε_r = 3.6 for different values of L3

From the three cases studied in the first example, we observe that the length L in each access port affects the operational frequency and likewise on the adaptation to the operational frequency itself

B. *Second example (ε_r = 4.3)*

The circuit used for this example is printed on a FR4 dielectric substrate of a constant thickness h=1.6 mm and a relative permittivity ε_r = 4.3. The other parameters are similar to the first example

1) *Effect of the variation of the length L1*

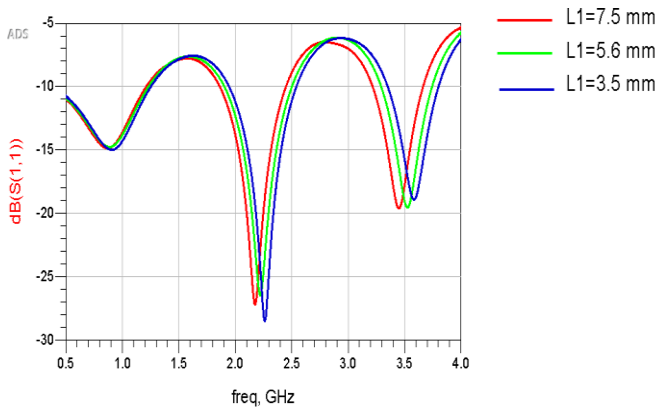

Fig. 11. Evolution of Wilkinson's coefficient S11 with a substrate of εr = 4.3 for different values of L1

2) *Effect of the variation of the length L2*

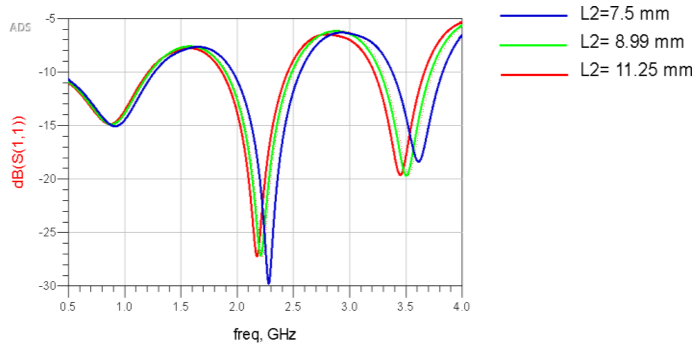

Fig. 12. Evolution of Wilkinson's coefficient S11 with a substrate of ε_r = 4.3 for different values of L2

It can be seen that the value of the operational frequency is proportionally inverse with the value of the length L2

3) Effect of the variation of the length L3

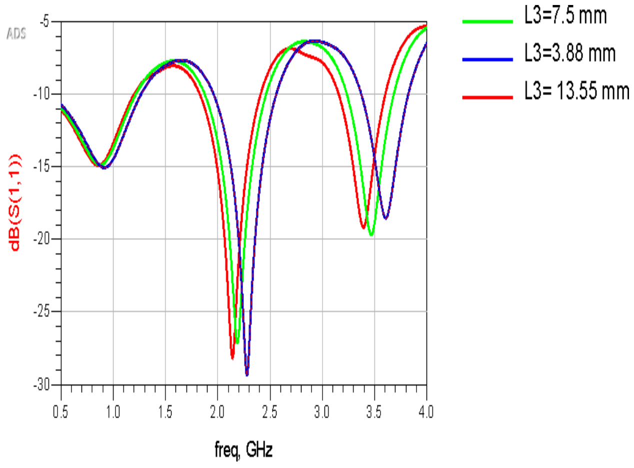

Fig. 13. Evolution of Wilkinson's coefficient S11 with a substrate of ε_r = 4.3 for different values of L3

Likewise for this second example the length L in each access port affects the operational frequency and likewise on the adaptation to the operational frequency itself

IV.2 Wilkinson Power Divider with *Meanders*

In this section, we will study the effect of the number of meanders on the evolution of the different scattering parameters.

The FR4 substrate is used with a relative permittivity εr = 4.3, constant thickness h = 1.6 mm, and angle of loss tg (α) = 0.0023.the thickness of the copper is considered equal to 35 µm

Step 1: WPD with a single meander

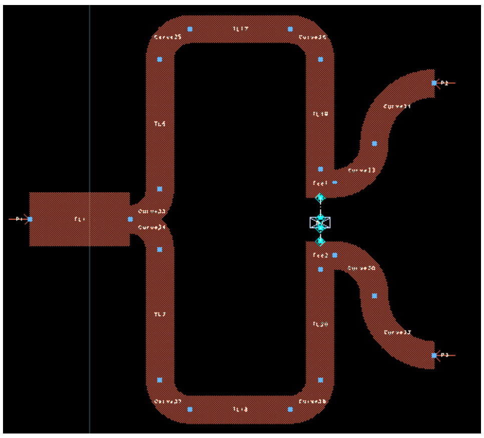

Fig. 14. The printed circuit of a Wilkinson divider with a single meander

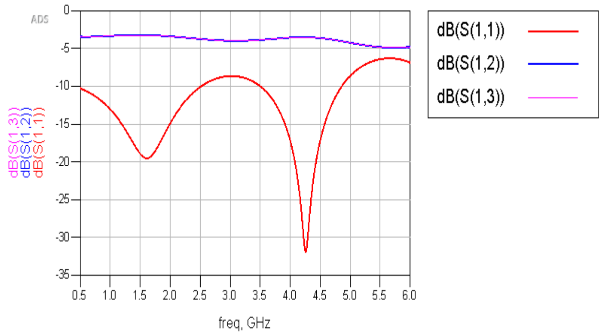

Fig. 15. The evolution of the different S parameters of the WPD with a single meander.

Step 2: WPD with two meanders

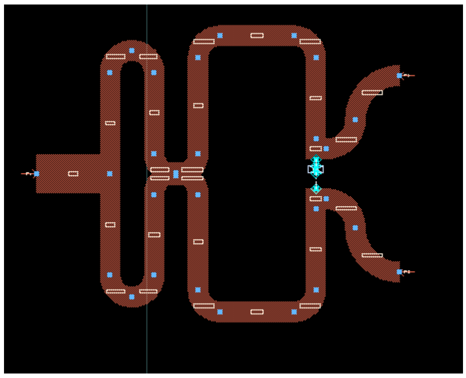

Fig. 16. The printed circuit of a WPD with two meanders

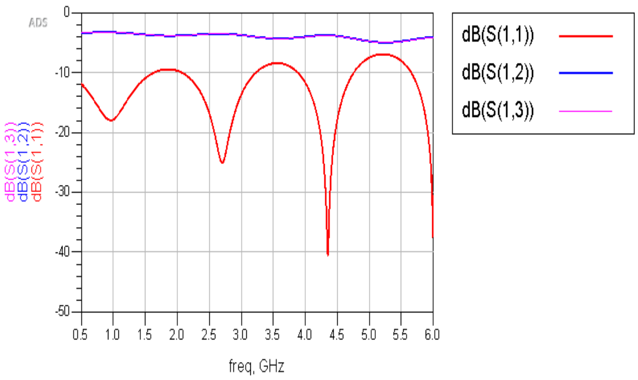

Fig. 17. The evolution of the different S parameters of the WPD with two meanders

Step 3: WPD with three meanders

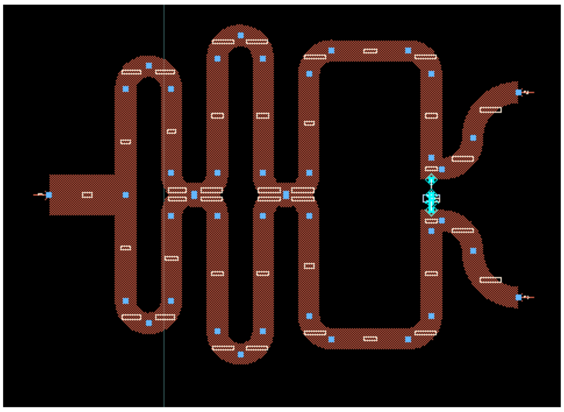

Fig. 18. The printed circuit of a WPD with three meanders

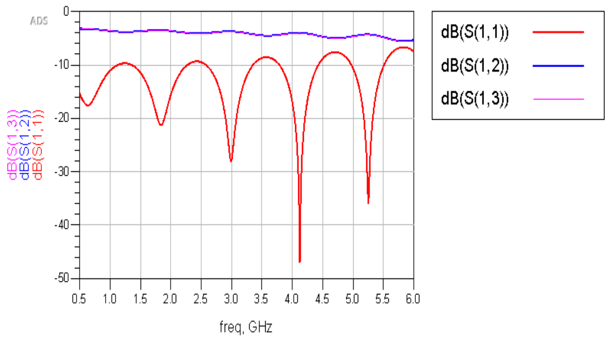

Fig. 19 The evolution of the different S parameters of the WPD with three meanders

Step 4: WPD with four meanders

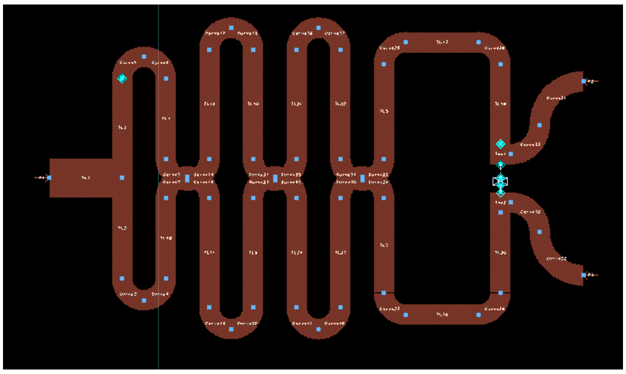

Fig. 20. The printed circuit of a WPD with four meanders

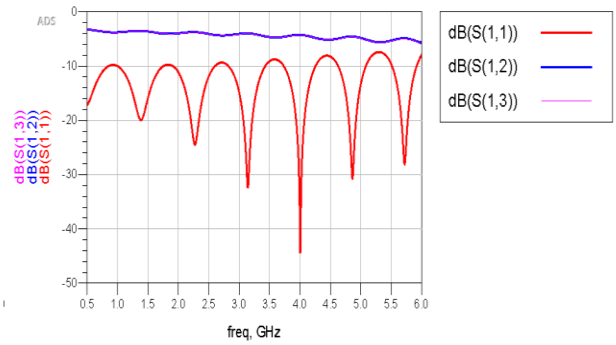

Fig. 21. The evolution of the different S parameters of the WPD with four meanders

Step 5: WPD with five meanders

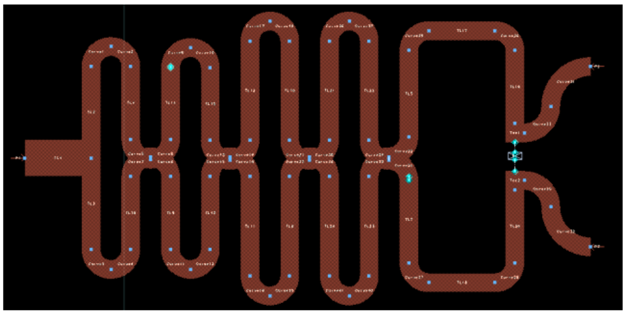

Fig. 22 The printed circuit of a WPD with five meanders

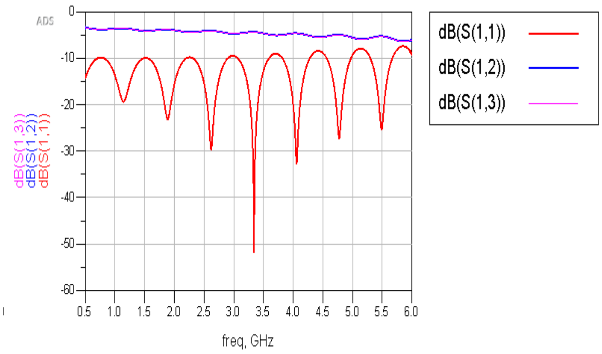

Fig. 23 The evolution of the different S parameters of the WPD with five meanders

From this parametric study of a Wilkinson divider, it is found that the number of meanders directly affects the occurrence of other operational frequencies. That is, each meander plays a role of a resonator.

V.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 15.

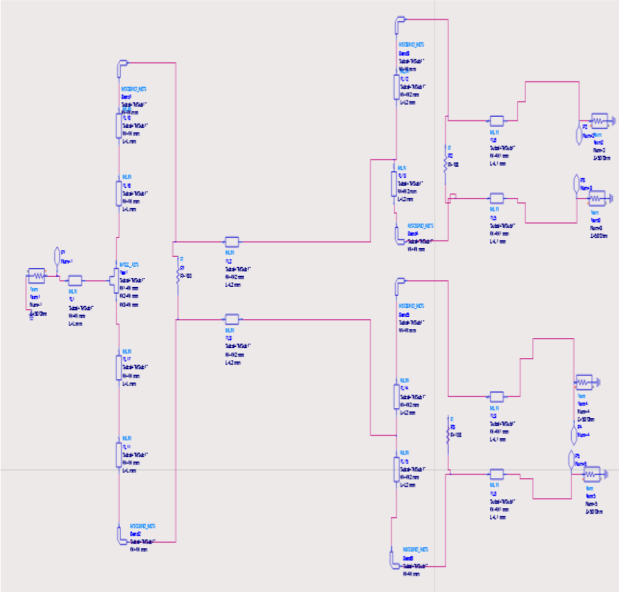

Fig. 25. Schematic circuit of the proposed four-port dual-band power divider using ADS.

The printed circuit of the previous diagram is shown in the Fig 26.

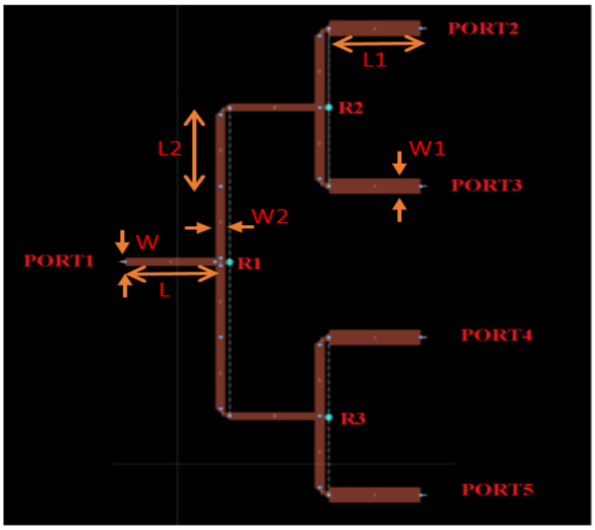

Fig. 26. The layout circuit of the proposed power divider.

VI.RESULTS AND DISCUSSION

Before starting the optimization process, the different objectives have to be defined, as in Fig 27.

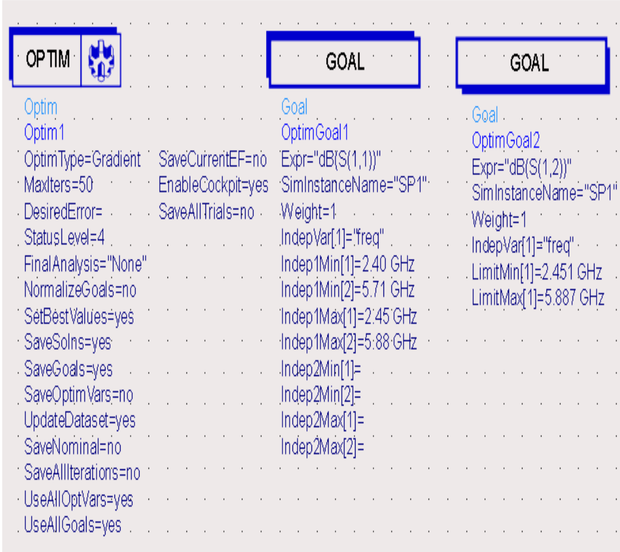

Fig. 27. Setting goals on ADS.

As shown in Fig 27, the type of optimization uses the grdient and the maximum number of iterations is fixed by 50. The goal we want to reach is the optimization of the 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:

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

Mathematically, this goal can be expressed using the following cost function

$$CF1 = \begin{cases} \min(|S_{11}|) & f \in [2,\ \ 3GHz] \cup [5, 6\ GHz] \\ & 0\ elsewhere \end{cases}$$

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:

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

The corresponding cost function is given by

$$CF2 = \begin{cases} \max(|S_{12}|) & f \in [2,\ \ 3GHz] \cup [5, 6\ GHz] \\ & 0\ elsewhere \end{cases}$$

The general form of the cost function used to obtain both objectives is given by:

$$CF = \alpha\ CF1 + \beta\ CF2$$

where α and β are ponderation weights.

TABLE 2. DIFFERENT DIMENSIONS OF DUAL-BAND POWER DIVIDER SHOWN FOR EACH ITERATION

Iteration \ (mm)	L	W	L1	W1	L2	W2
Initialization	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

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 2).

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.

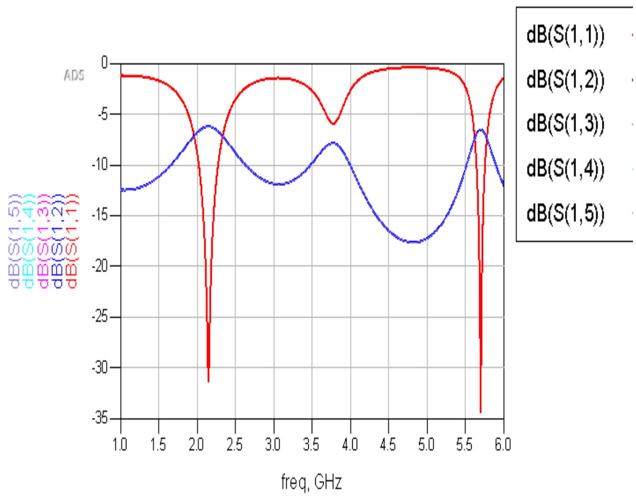

Fig. 28. The responses of the different distribution parameters for the initial vector.

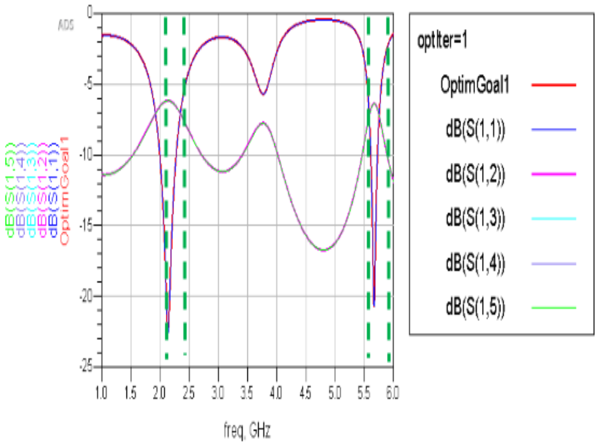

Fig. 29. The responses of the different distribution parameters for the optimal vector after the 1st iteration.

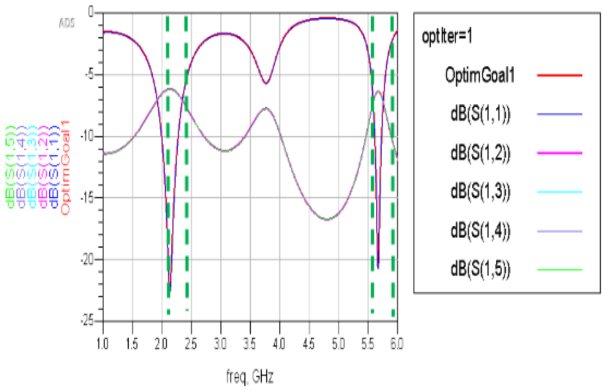

Fig.30. The responses of the different distribution parameters for the optimal vector after the 2nd iteration.

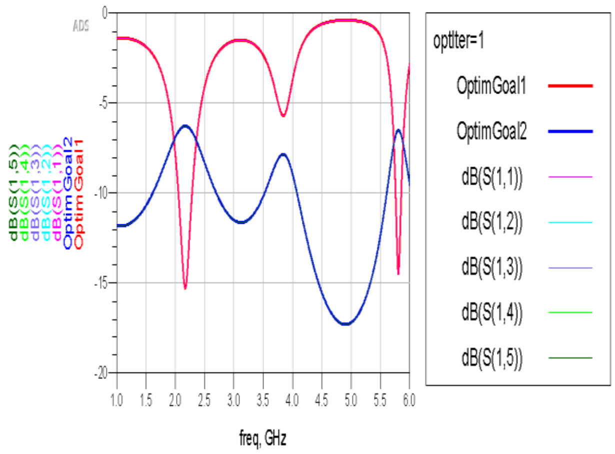

Fig.31. The responses of the different distribution parameters for the optimal vector after the 3rd iteration**.**

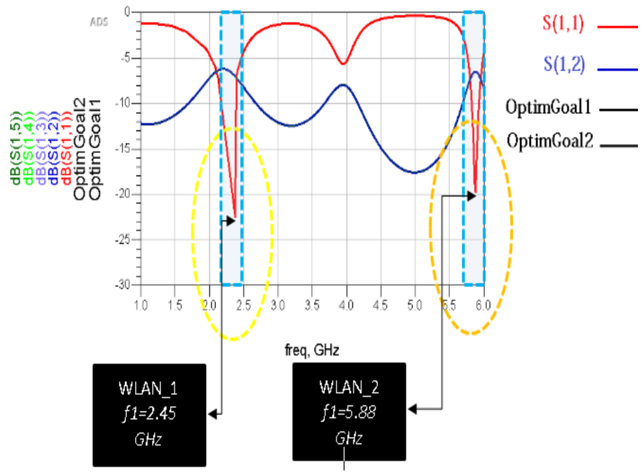

Fig.32. The responses of the different distribution parameters for the optimal vector after the 4th iteration.

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 28 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 Wilkinson 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 The obtained results illustrate the effectiveness of the GA in optimization problem for the designed WPD in terms of adaptation and isolation at the dual band of WLAN applications (f1 = 2.45 GHz and f2 = 5.8 GHz).

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