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A novel design of a reconfigurable power divider with stubs for mobile applications

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ABSTRACT

Nowadays, the world knows a huge revolution in telecommunications, which has led to the need to integrate many services, such as long-term evolution (LTE), 5G, wireless local area network (WLAN), and Bluetooth, in one receiving and transmitting device. In the same way, all active and passive microwave circuits must be compatible with the integration of services, including the power divider, which is the subject of our work. This passive component is used in several fields such as medicine, surveillance, radar systems and others applications. Wilkinson divider is one of the most prominent power dividers, it is classified as narrow-band power divider and it is a very useful component in mobile applications (2.4 and 5.8 GHz). In this work, a reconfigurable 4-ports Wilkinson divider is designed using PIN diodes and simulated using computer simulation technology (CST) simulator software. This designed divider can easily modify the operation mode by activating or disabling the PIN diodes.

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1. INTRODUCTION

Power dividers are considered among the most popular passive circuits in RF and microwave domain [1], [2]. They are widely used in frequency multipliers, balanced amplifiers, mixers, antenna arrays, and are particularly used to ensure antennas array feeding. The main role of a power divider is to divide a given input signal into two or more signals according to the needs of the circuit or system. Wilkinson power divider (WPD) is a lossless divider, with matched impedance in all ports, and isolation between all output ports [3].

The evolution and development of modern wireless telecommunications increasingly necessitates the use of multi-band and multi-functionality systems. For example, due to the dual-band requirement in wireless communication systems (GSM, UMTS, and LTE), the use of reconfigurable antennas is required [4]-[8]. However, these antennas cannot be completely realized without using an advanced feeding network [9]-[11]. Reconfigurable WPD becomes paramount components of many microwave circuits. In antenna feeding systems, WPD is commonly used to combine and distribute power [11]-[15].

Zhang and Che [16] try to integrate a coupler and filter in order to design a power divider designed for radar applications. However, this design is difficult and cannot be reconfigured. In addition, to achieve reconfigurability properties, researchers mainly use varactor diodes in their power divider designs [16]-[22], but this leads to an increase in design complexity. Zhou *el al.* [23], a reconfigurable WPD is achieved by modifying the value of voltage and electrifying the lower and upper surface electrode of the liquid crystal. However, the design process is also very complex. In addition, for the design of a power divider, the PIN diode can be used to achieve reconfigurability properties [24], [25]. Therefore, this work proposes the design and simulation of a modified reconfigurable WPD for WiMAX standards, at 2.5 GHz and 3.5 GHz. The proposed design includes two conventional WPDs. These power dividers are modified to obtain different operating frequencies, which cannot be achieved by using a single power divider.

Thus, our paper presents a compact multiport reconfigurable WPD with an overall dimension of 45x95x1.6 mm^3. The reconfigurability of the proposed WPD is done using four PIN diodes. Our paper is organized as follows: After an introduction in first section, we present the design of a four-port dual-band Wilkinson power divider in section 2. Section 3 is devoted to results and analysis. Finally, main conclusions are drawn in section 4.

2. DESIGN AND SIMULATION OF A FOUR-PORT DUAL-BAND WPD

The design of our Wilkinson power divider, in computer simulation technology (CST) software, consists of performing many steps. First, a Wilkinson divider with a complete ground plane is chosen. The proposed divider is then designed on a low-cost substrate (FR4 lossy) with the following parameters: dimension=95×45 mm^2 (length×width), relative permittivity ε_r=4.3, dielectric loss tangent tan δ=0.025, thickness h=1.6 mm and the copper thickness t are approximately 0.035 mm. The dimensions of the ground plane are the same than those of the substrate (length×width). The power divider is directly connected to a feeding line whose characteristic impedance is equal to 50 Ω. The effective dielectric constant used in the modeling of our power divider is (1).

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r+1}{2}\right) + \left(\frac{\varepsilon_r-1}{2}\right)\left(1 + 10\frac{h}{W}\right)^{-\frac{1}{2}} \quad (1)$$

To have matched impedance, one must use the impedance calculator of the CST software for the model corresponding to antennas powered by a feeding line. This calculator is based on Wheeler's synthesis equations. So, to have an input impedance of 50 Ω, one must use a feeder width W_f of 3 mm for a height of the substrate h=1.6 mm.

The proposed structure of our four-port Wilkinson power divider is shown in Figure 1. The initial dimensions adopted of this Wilkinson power divider are given in Table 1. The initial dimensions, mentioned in Table 1, permit to achieve a simulated S11 parameter of the proposed WPD with stubs as illustrated in Figure 2. The power divider presents a good adaptation across the frequency band from 1.6 to 2.2 GHz but this is not enough to make it useful for wireless local area network (WLAN) applications. For that, other stubs will be added. The stubs are used with PIN diodes to ensure the frequency reconfigurability.

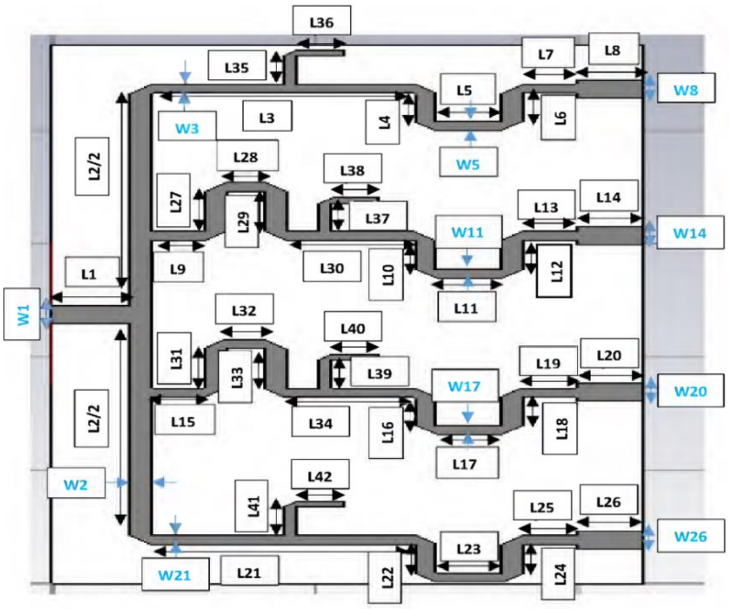

Figure 1. Structure of the proposed four-port Wilkinson divider

Table 1. The dimensions of the proposed power divider

Parameter	Value (mm)	Description
LG	95	ground plane/substrate length
WG	45	ground plane/substrate width
L1	6	length of the first line
W1	3.137	width of the first line
L2	78	length of the second line
W2	1.6	width of the second line
L3	20	length of the third line
L4	5	length of the fourth line
L5	5	length of the 5th line
L6	5	length of the 6 th line
L7	4	length of the 7th line
L8	5.20	length of the 8th line
L9	4	length of the 9th line
L27	7	The length of the line 27
L28	3	The length of the line 28
L30	9.8	The length of the line 30
L35	3	The length of the stub
W35	1	The width of the stub
L36	4	The length of the stub
W36	1	The width of the stub

Note that:
L21=L3=20 mm., L10=L11=L12=L16=L17=L18=L22=L23=L24=L4=5mm.,
L13=L19=L25=L7=4 mm., L14=L20=L6=L8=5.20 mm., L15=L9=4 mm.,
L29=L31=L33=L27=7 mm., L32=L28=3 mm, L34=L30=9.8 mm,
L37=L39=L41=L35=3 mm., L38=L40=L42=L36=4 mm.
W14=W20=W26=W1=3.137 mm,
W37=W38=W39=W40=W41=W42=W35=1 mm,
W3=W4=W5=W6=W7=W9=W10=W11=W12=W13=W15=W16=W17=
W18=W19=W21=W22=W23=W24=W25=W2=1.6 mm.

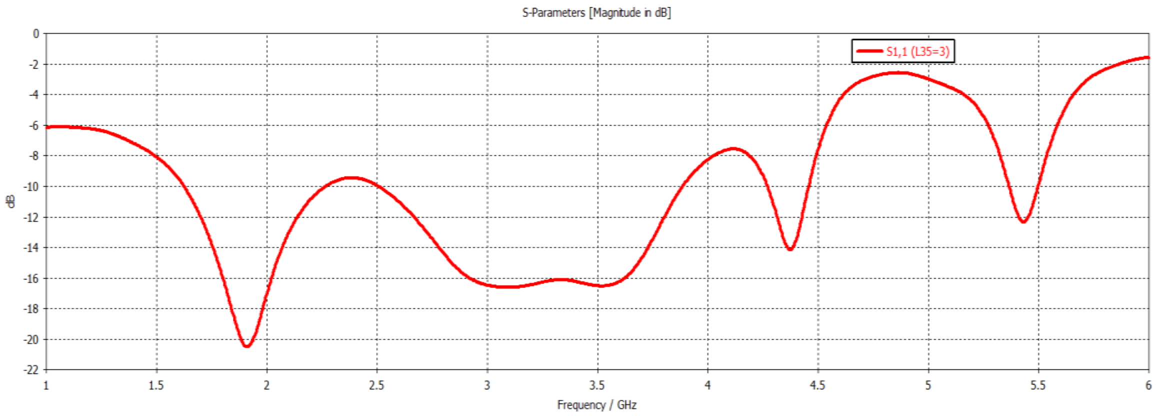

Figure 2. Reflection coefficient S_{11} for the proposed divider with the dimensions listed in Table 1

3. RESULTS AND ANALYSIS

The traditional WPD is formed by microstrip lines printed on a given substrate. In our proposed WPD, the divider is designed using L shape stubs as shown in Figure 3. In order to make the WPD reconfigurable in frequency, we must add pin diodes [26] (which can take two states: ON, OFF) to the proposed structure.

3.1. PIN diode modeling

Generally, a PIN diode can be modeled using two equivalent impedance circuits. The first impedance circuit is designed to provide the ON state while the second one is used to model the OFF state. In our paper, to model the two states of the PIN diode, we ha ve used a piece of metal for the ON state and a discontinuity of the metallic strip for the OFF state.

3.2. Design of the reconfigurable Wilkinson power divider

The designed Wilkinson power divider has an operational frequency of about 5.8 GHz with a bandwidth ranging from 5.67 GHz to 5.91 GHz. This band covers the second WLAN band. Figure 3 shows a

1x4 Wilkinson power divider optimized with CST simulation software. This divider contains two rods with inverted L shape for the two external transmission lines. The second L has another rod perpendicular to the delay line as shown in Figure 3.

3.2.1. All diodes are in ON state

In Figure 3, we present the structure of our WPD with four diodes. When all the diodes are in ON state, the obtained reflection coefficient S_{11} and the transmission coefficients are illustrated in Figure 4. The simulated S_{11} of the WPD, with four PIN diodes in ON states, is shown in Figure 4. In this case, the WPD works well across the first WLAN band (around 2.4 GHz).

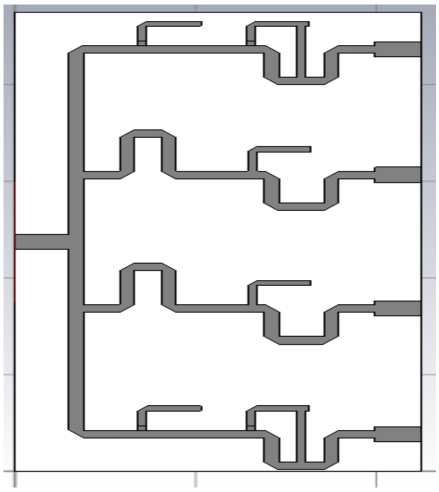

Figure 3. WPD with four PIN diodes in ON state

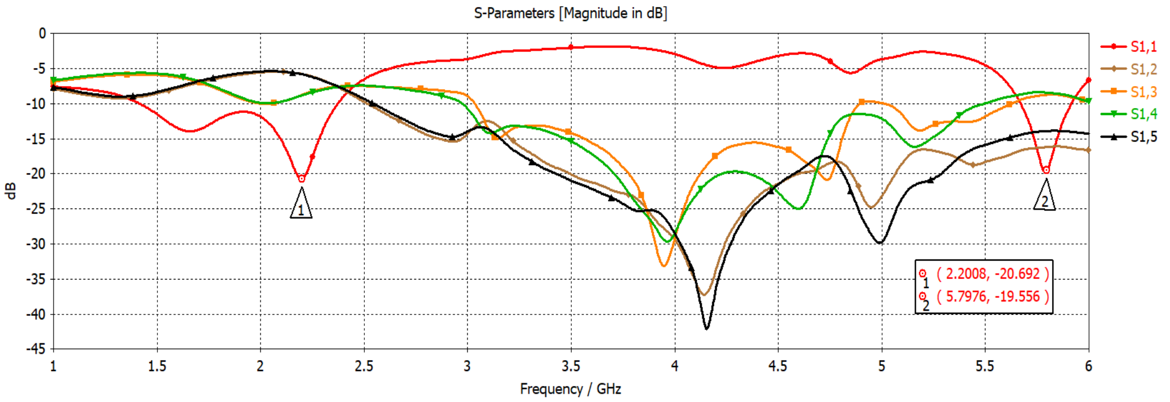

Figure 4. Reflection coefficient S_{11} and some transmission coefficients for the case of four diodes in ON state

3.2.2. All diodes are in OFF state

In this case, all the PIN diodes are kept in the state OFF as shown in Figure 5; the obtained reflection and transmission coefficients are presented in Figure 6. This figures shows that with stubs, our circuit operates in a wide band of 3.5 GHz to 4.5 GHz with a reflection coefficient S_{11} of -25 dB. This frequency band presents a particular interest for 5G applications.

3.2.3. Two diodes OFF and the other two ON

As illustrated in Figure 7, the two diodes circled in blue are OFF while the other two diodes circled in red are ON. The reflection coefficient S_{11} and some transmission coefficients for this ON-OFF state are presented in Figure 8, which shows that the simulated reflection coefficient operates primarily in two bands. These bands, corresponding to WLAN applications, are located around 2.4 GHz and 5.8 GHz. The following

Table 2 summarizes the important characteristics illustrated from the different results reported in Figures 4, 6, and 8.

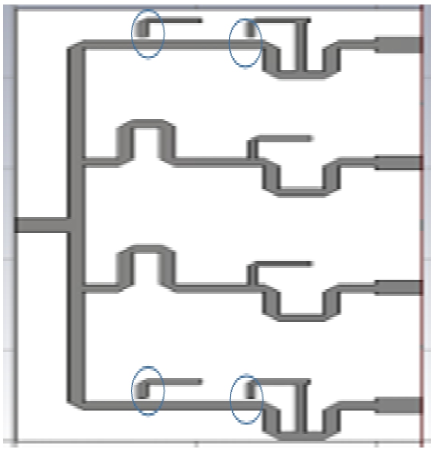

Figure 5. WPD with four diodes in OFF state

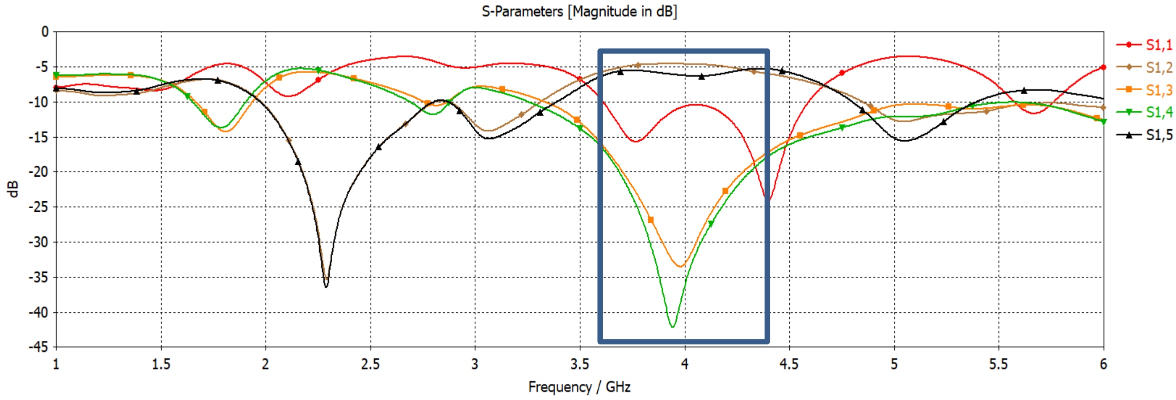

Figure 6. Scattering coefficients for the case of four PIN diodes in OFF state

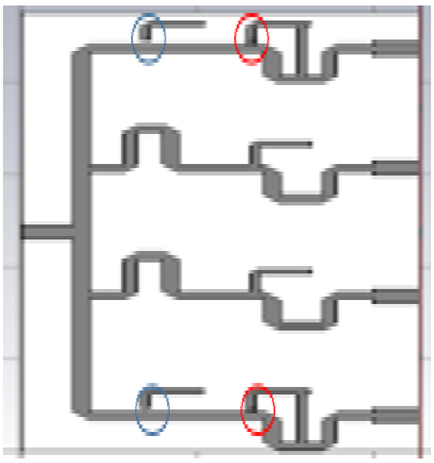

Figure 7. WPD with two diodes OFF while the other two diodes are ON

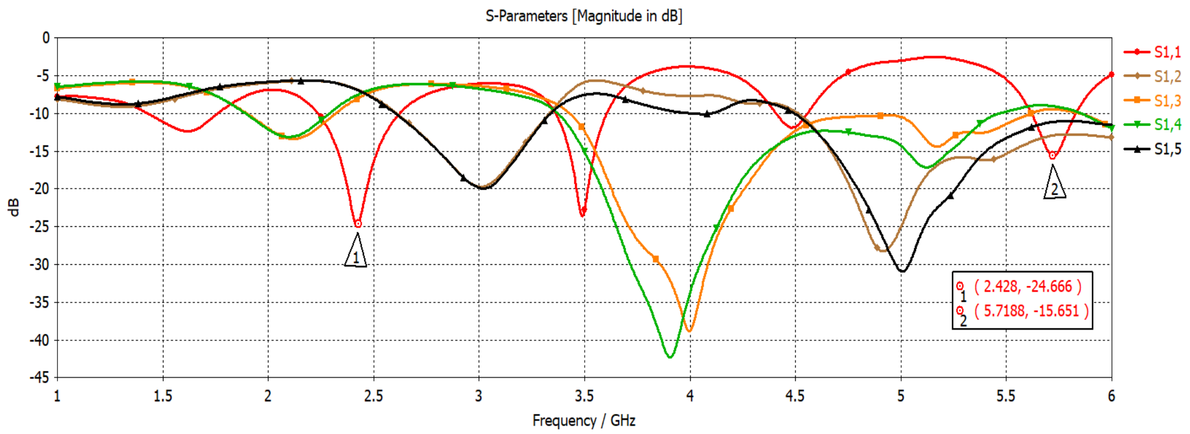

Figure 8. Some scattering coefficients for PIN diodes in 2 OFF-2 ON state

Table 2. Some characteristics illustrated from the different results reported in Figures 4, 6, and 8

States of diodes D1 D2 D3 D4	No. of resonating bands	Frequency of resonance (GHz)	Operating range of interest (GHz)	Return loss (dB)
0000	3	3.75; 4.4; 5.7	3.61-4.59	-25
0011	5	1.62; 2.42; 3.5; 4.5; 5.8	2.24-2.62	-25
			5.6- 5.83	-16
1100	2	1.93; 5.76	5.63-5.90	-16
1111	3	1.6; 2.2; 5.8	5.65-5.92	-19.5

3.2.4. Isolation

To study the isolation between the different output ports (port 2 with port 3 and port 4 with port 5), we plotted in Figure 9 the isolation parameters S_{32} and S_{45} versus frequency, for the ON-OFF state. This Figure shows that the isolation parameters between 2 and 3 ports (S_{32}) and between 4 and 5 ports (S_{45}) are lower than -15 dB in the frequency band of interest [5.6 GHz - 5.9 GHz]. We also see, in this figure, that the proposed WPD with stubs presents an isolation (S_{32}, S_{45}) of -5 dB in the frequency band of interest (2.45 GHz).

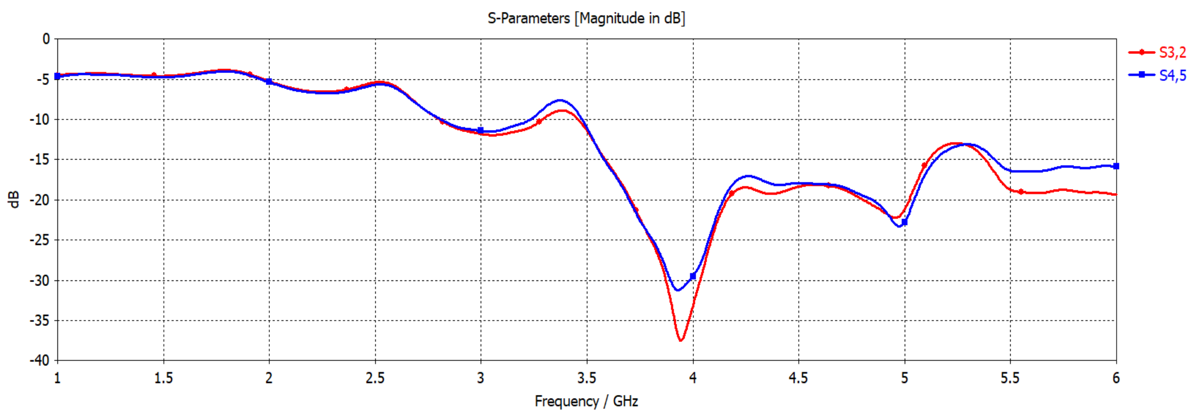

Figure 9. Isolation S_{32} and S_{45} for the ON-OFF state

4. CONCLUSION

In this research, we designed a reconfigurable power divider for mobile applications using the CST studio V.2019 software simulator. We started by positioning the envisaged work by presenting a state of the art on the different Wilkinson dividers, then we have proposed a Wilkinson divider with four output ports. Our goal was to make changes on the physical dimensions of the proposed divider until obtaining the two desired frequencies (f_1=2.45 GHz, f_2=5.8 GHz). Relevant results and good performances have been achieved with the proposed WPD. Formerly, the WPD operated at a fixed frequency, but today, with the development of scientific research, it is possible to control more than one frequency by means of PIN diodes.

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