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Design and EM Analysis of Dual Band Hilbert Curve Based Wilkinson Power Divider

Avneet Kaur†, Harsimran Singh, and Jyoteesh Malhotra
Department of Electronics & Communication Engineering, GNDU-RC, Jalandhar 144009, India

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In this paper, two configurations (T-type and Y-type) of dual band Wilkinson Power Divider based upon Hilbert curves are presented. Formerly, the concept of Hilbert Curves was implemented in only designing microstrip antennas. In power dividers, this is the very first attempt of incorporating them for size reduction. In addition to this, an effect of inculcation of high-dielectric constant layer (Hafnium-oxide, HfO_2, ε_r= 25) between a substrate and top metallization in both configurations was investigated. The proposed configurations are designed on a high resistive silicon substrate (HRS) for L and S bands with resonating frequencies of 1.575 and 3.4 GHz. Both configurations have return loss that is better than 20 dB and an insertion loss of around 6 dB; isolation better than 30 dB was achieved for both models.

Keywords: Wilkinson power divider, Hilbert curve, Microstrip, Hi resistive silicon, Dual band

1. INTRODUCTION

Power dividers are widely used components in various microwave communication systems such as power amplifiers, mixers, filters and antenna feed applications. Besides WPDs, T-junction and resistive type power dividers are also available. However, they are not usually employed because of their poor isolation between the output ports [1]. Thus, Wilkinson Power Dividers are preferred owing to the reason that they are lossless (if matched at all ports) while providing high isolation between the output ports [2]. Due to these properties, they also find various applications in the three major application areas of RF communication systems i.e. terminal, base and satellite. Conventional WPDs are single band power dividers that use a quarter wave transmission line to perform the required operation of power division [3]. However, with the growth of modern communication systems and crowding in operational frequency bands, the demand for multi-band devices have considerably increased for the dual band power dividers that have come into practice. Dual band power dividers resonate at ratio frequencies that range between 2 and 2.75 [4].

In this paper, design and EM analysis of two models (T-Type and Y-Type) of 4-way dual band Wilkinson Power Divider using Hilbert curves is presented. Hilbert curve is a space filling curve which is generated in iterations i.e. 0, 1, and 2. This design utilizes the second iteration of a Hilbert curve for size reduction. Besides, the application of Hilbert Curves in the designing of WPDs, insulating a layer of a high-dielectric constant is also inserted between the silicon substrate and top metallization. These high dielectric substrate layers help in lowering conductor losses, thereby, improving the circuit performance. The dividers are designed to operate at 1.575 GHz (L-Band) and 3.400 GHz (S-Band) on a high resistive silicon substrate (ρ>8 kΩ, h=675 μm, tanδ=0.001 and ε_r=11.8). Design and Optimization of the proposed models were carried out using FEM based electromagnetic tool for the entire frequency band of 1~4 GHz.

2. DESIGN METHODOLOGY

In this paper, dual band configurations of Wilkinson Power Divider, based on Hilbert Curves, are explored. A detailed design methodology along with design equations are presented in the following sections.

† Author to whom all correspondence should be addressed:
E-mail: avneetkaur.53@gmail.com

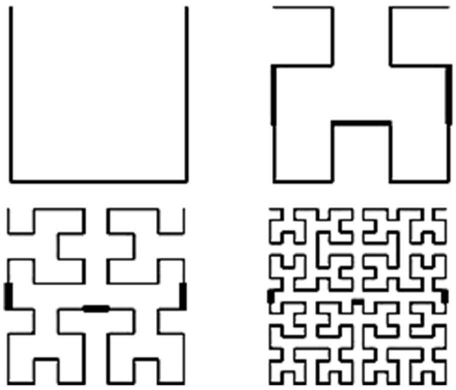

Fig. 1. Iteration levels of Hilbert curves.

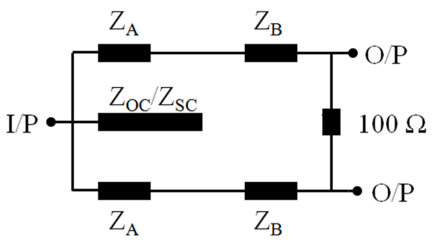

Fig. 2. Conventional dual band topology of 1:2 Wilkinson Power Divider.

2.1 Hilbert curves

Hilbert curve is a type of space filling fractal curve that finds its application in various microwave circuits due its ability to efficiently use available physical space. These curves are generated in iterations by successively repeating one geometrical shape, which results into the formation of a higher order fractal curve. This higher order curve effectively covers the physical area in which it is generated, thus helping in miniaturization of the infinite-length transmission line on a given substrate [5]. Due to this property, the Hilbert Curve has become an attractive choice for use in the design of power dividers and fractal antennas for size reduction. Representation of various iteration levels of these curves is shown in Fig. 1.

2.2 Dual band 1:2 Wilkinson power divider

The designed 2-way dual band configuration of WPD consists of cascaded high and low impedance quarter-wave line sections for connection between the input and output ports. An open circuit stub for proper impedance matching is employed, as shown in Fig. 2 [6].

$$Z_A = \sqrt{2} Z_0 \, tan \frac{\pi}{2} \varepsilon \quad (1)$$

$$Z_B = \sqrt{2} Z_0 \tan \frac{\pi}{2} \varepsilon \quad (2)$$

$$Z_{SC} = \frac{Z_0}{2} \frac{tan \pi\varepsilon}{\sqrt{2}} \tan^2 \frac{\pi}{2} \varepsilon \quad (3)$$

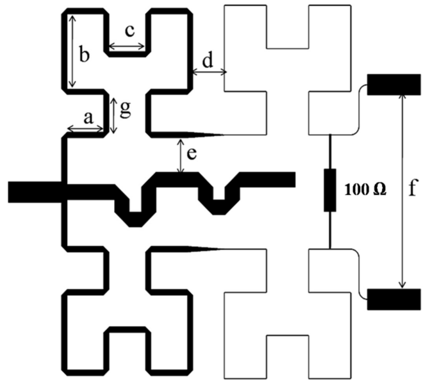

Fig. 3. Dual band hilbert curve based 1:2 Wilkinson power divider.

Table 1. Physical parameters of hilbert curve in WPD.

Parameters	Value (mm)
a	1.36
b	2.73
c	1.57
d	1.28
e	0.96
f	6.28
g	1.36

$$Z_{OC} = \frac{Z_0}{2} \frac{\tan^2 \pi\varepsilon}{\sqrt{2}} \tan \frac{\pi}{2} \varepsilon \quad (4)$$

Where Z_0=Char. Impedance, Z_{SC}=Short Circuit Impedance Z_{OC}=Open Circuit Impedance and □ and f_0 are given by,

$$\varepsilon = \frac{(f_2/f_1)-1}{(f_2/f_1)+1} \quad (5)$$

$$f_0 = \frac{f_1 + f_2}{2} \quad (6)$$

Based on the above equations, Eqn. (1)~(6), [6] the measured values of Z_A, Z_B and Z_{OC} are 45.90 Ω, 108.89 Ω, and 57.79 Ω, respectively. Incorporating a second iteration of Hilbert Curves in its two cascaded quarter wave line sections is done by size reduction of the power divider. Also, to decrease the length of the open-circuited stub, meandering is done, as shown in Fig. 3, along with the detailed dimensioning tabulated in Table 1.

3. DUAL BAND 1:4 WILKINSON POWER DIVIDER

The four-way dual band Wilkinson Power Divider, presented in this paper, is an integration of a single frequency 1:2 WPD with 2-way dual band WPDs designed using the Hilbert Curve iteration. Further, two models of dual band 4-way WPDs are discussed, namely the T-Model and Y-Model [7].

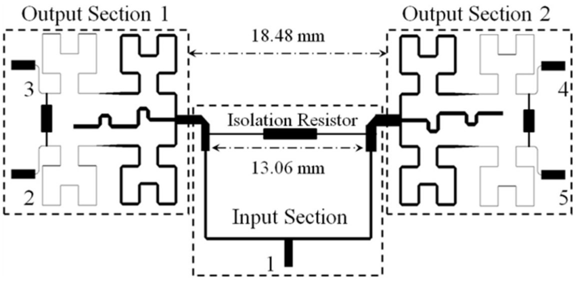

Fig. 4. Layout of T-model of 1:4 dual band hilbert curve WPD.

3.1 T-model

The proposed structure consists of three 2-way Wilkinson Power Divider sections connected in a T-type configuration. Output ports are at a right angle with respect to the input port as shown in Fig. 4. The output sections of dual band 1:2 WPDs operate at a frequency of 1.575 GHz (f_1) and 3.4 GHz (f_2). These sections are constructed using high and low impedance lines cascaded together through a gradual width reduction in order to avoid odd-mode resonance aroused due to a step transformation in the width. The input section is a simple 2-way WPD operating at an average of f1 and f2 frequencies, constructed using a quarter-wavelength transmission line of impedance $\sqrt{2}Z_0$, (Z_0= 50 Ω) and an isolation resistor (100 Ω). The distance between the output ports of the input section and output sections are13.06 mm and 6.28 mm, respectively. To achieve miniaturization in high and low impedance transmission line of the circuit, a second iteration of the space filling Hilbert Curves is used. Thus, the overall cover area of T-type dual band 1:4 WPD is '43.2×15.7' mm.

3.2 Y-Model

In this configuration, the three sections of 1:2 WPDs are connected in a manner where the overall structure looks like a 'Y' shape as shown in Fig. 5. Single band 2-way Wilkinson Power Divider forms the input section of the circuit. The quarter-wavelength line is divided into two equal halves which are connected together using a microwave bend, thus, reducing the overall length of the input section. The output sections are the dual band 1:2 Hilbert Curve based WPDs connected in such a way that all the output ports are along the same axial plane. Distance between the output ports of the input section is 13.72 mm and the overall cover area of the Y-model is '25.4×30.4' mm.

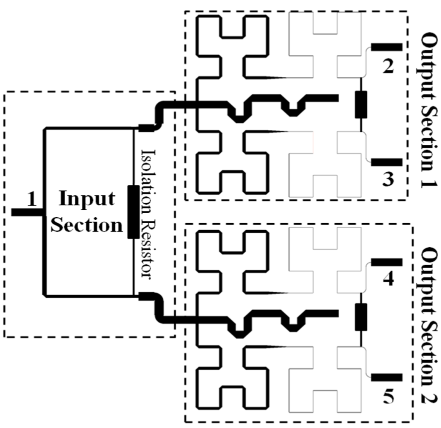

Fig. 5. Layout of Y-type 1:4 dual band hilbert curve WPD.

4. EFFECT OF DIELECTRIC

Inculcation of the insulating layer of the high dielectric constant [8,9] in construction of microwave and millimeter wave devices improvise their performance and explicate their functionality by reducing conductor losses and induce at a higher frequency due to arousal of odd modes of propagation [10]. In the proposed structures, Hafnium oxide (ε_r=25) of thickness 1.5 μmis inserted between the HRS substrate and top metallization to induce decaying fields in the insulator. This usually reduces the field strength at the conductor surface, thereby, narrowing down the conductor losses.

Apart from diminished conductor losses, using a high-dielectric substrate yields two more advantages at a higher frequency: lower impedance and compact circuits. The formal apprehends high power handling traits of semiconductors, making impedance matching easier and imperative [11].The performance comparison of both T-Type and Y-Type models (with and without hafnium oxide) of 1:4 dual band WPD has been investigated.

5. RESULTS AND DISCUSSIONS

Both the configurations of 1:4 Wilkinson Power dividers are analyzed in commercially available FEM solvers [12]. Structures

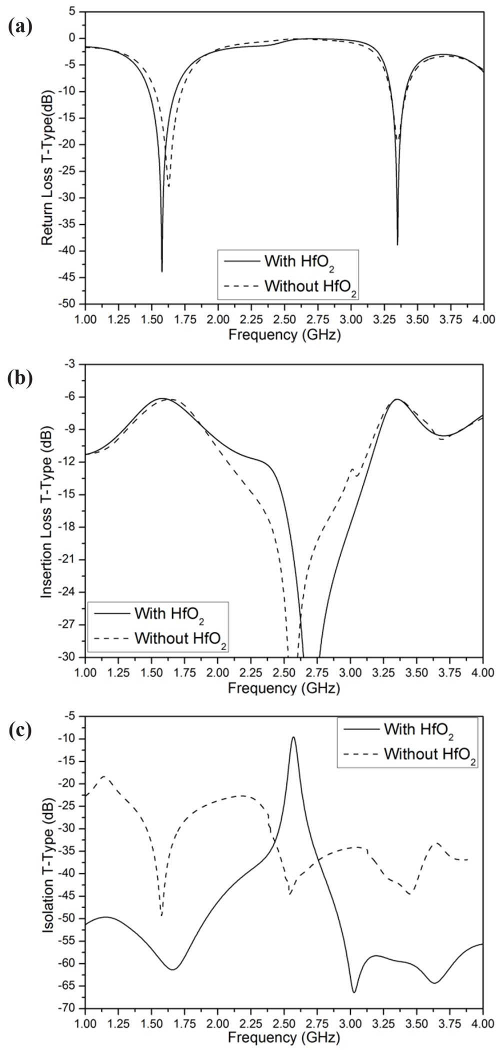

Fig. 6. Results of T-type 1:4 dual band. (a) Return loss, (b) insertion loss, and (c) isolation.

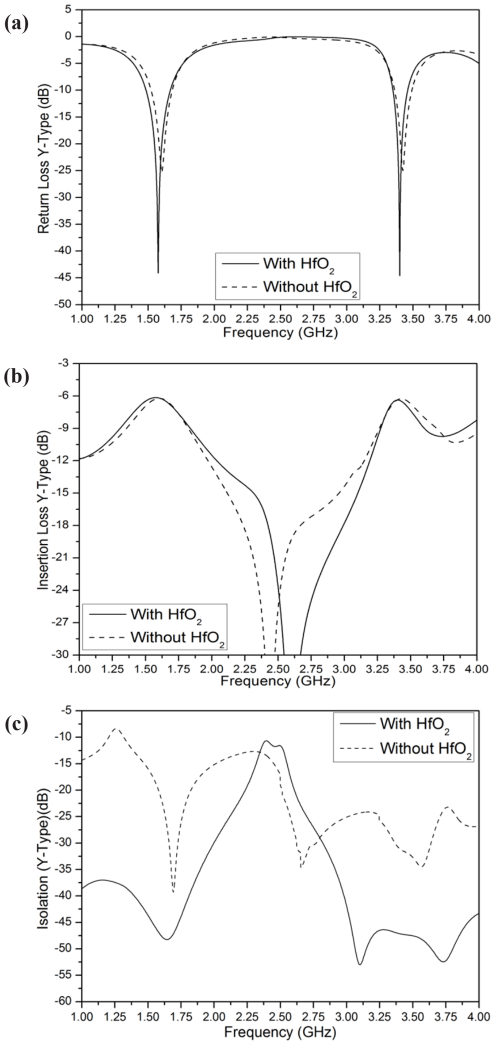

Fig. 7. Results of Y-type 1:4 dual band WPD. (a) Return loss, (b) insertion loss, and (c) isolation.

Table 2. Performance comparison of Hilbert Dual Band WPD.

Parameters		T-Type		Y-Type	
		Without HfO_2	With HfO_2	Without HfO_2	With HfO_2
Return Loss(dB)	@1.575GHz	-28.169	-44.427	-20.720	-43.542
	@3.4GHz	-19.176	-39.742	-25.519	-44.490
Insertion Loss(dB)	@1.575GHz	-6.349	-6.125	-6.282	-6.151
	@3.4GHz	-6.428	-6.480	-6.358	-6.301
Isolation (dB)	@1.575GHz	-49.279	-60.129	-34.123	-48.009
	@3.4GHz	-43.197	-59.635	-31.036	-47.130
Cover Area (mm^2)		43.2 × 15.7		25.4 × 30.4	

are simulated on a high resistive silicon substrate (ρ>8 kΩ, h=675 μm, tanδ=0.001, and ε_r=11.8) for the frequency range of 1-4 GHz. RF performances of T-Type and Y-Type 1:4 dual band WPDs are shown in Fig. 6 and Fig. 7. Table 2 summarizes the comparative performance study of both the dividers.

From the above graphs, it is clear that the addition of dielectric layers increase the return loss value of power divider circuits. For T-Type dual band WPDs, return loss values increase to -44.427 dB and -39.742 dB from -28.169 dB and -19.176 dB at 1.575 and 3.4 GHz, respectively, whereas for Y-Type Wilkinson power divider, it is increased by more than -18 dB at both the operating frequencies. Thus, improving the performance of the designed dual band WPDs.

6. CONCLUSIONS

Both the configurations of dual band 4-way (T-Type and Y-Type) WPDs have been analyzed and simulated. The incorporation of an insulating layer, of a high-dielectric constant, for reducing conductor losses and Hilbert Curves for reduction of divider size is the novel feature of the proposed designs. At the operating frequency of 1.575 GHz, the return loss of T-type model is better than that of the Y-type whereas at 3.4 GHz, the value of the Y-Type is more than that of the T-Type by -4dB, irrespective of the addition of a dielectric layer. Also, the isolation of the T-Type model is -12 dB more than that of Y-type at both the operating frequencies. However, both the models provide a quaternary (-6 dB) power division at 1.575 and 3.4 GHz with or without HfO_2. In terms of the total area covered, the Y-Type configuration covers 94 mm^2 more than the T-model. So, in aerospace and space borne systems, power division blocks are used because of their high return loss and compactness. In those scenarios, output ports that are perpendicular to the input will be useful as it reduces the print area where numerous other circuit elements can be placed for the complete system design. Here, the T-type 4-way WPD is found to be very useful. However, when output ports are required along the same axis for an antenna feeding network, their Y shape design will be a potential choice. Overall, both the configurations provide a high return loss and good isolation between the output ports, which is a major requirement in the design power dividers.

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