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Application Article

Optimized Ultrawideband and Uniplanar Minkowski Fractal Branch Line Coupler

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The non-Euclidean Minkowski fractal geometry is used in design, optimization, and fabrication of an ultrawideband (UWB) branch line coupler. Self-similarities of the fractal geometries make them act like an infinite length in a finite area. This property creates a smaller design with broader bandwidth. The designed 3 dB microstrip coupler has a single layer and uniplanar platform with quite easy fabrication process. This optimized 180° coupler also shows a perfect isolation and insertion loss over the UWB frequency range of 3.1–10.6 GHz.

1. Introduction

Recently, ultrawideband technology has been used in many branches of science and wide range of applications such as radars, navigation, telemetry, mobile satellite communications, biomedical systems, the direct broadcast systems, and remote sensing utilities. The design of an appropriate microwave device for these systems is one of the major challenging tasks.

Microstrip power divider and coupler designs and topologies which achieved compact size and broadband operation of the component could be categorized in some major methods including

(a) wideband stub matching,
(b) multistaging of the ordinary components,
(c) multilayer and multiwafer packaging technologies,
(d) deforming the shapes and using alternative geometries.

As an instance of the first category, a 3 dB power divider on microstrip line is analyzed and designed in [1] using UWB stub matching technique. This divider is formed by installing a pair of stepped-impedance, open-circuited stubs, and parallel-coupled lines to two symmetrical output ports.

Also in this class, an UWB microstrip power divider with good isolation and sharp roll-off skirt is proposed in [2]. By introducing a pair of quarter-wavelength short-circuited stubs and parallel-coupled lines to 2 symmetrical output ports, good performance in terms of equal power splitting is achieved. By virtue of direct-current chocked and half-wavelength transmission zeros of short-circuited stubs, out-of-band roll-off skirt near the cutoff frequencies is sharpened.

Multistaging of the well-known Wilkinson power divider is used in [3] to achieve an UWB coplanar waveguide balun for operation over 800–5000 MHz. Another well-established example of the multistaging method is proposed in [4]. Thereby, an optimized microstrip 3-stage Wilkinson power divider based on lowpass filter is presented. The particle swarm optimization method and method of moment have been used to broaden the bandwidth to effectively cover 1–8 GHz which is equal to 155.6% fractional bandwidth.

Multistaging of the T-junctions in slot line topology has also been presented in [5]. This compact and out-of-phase uniplanar power divider operates over the ultra wideband frequency range.

The third alternative category is to use multilayer substrates. A multilayer in-phase power divider with ultrawideband behavior is presented in [6]. The proposed divider

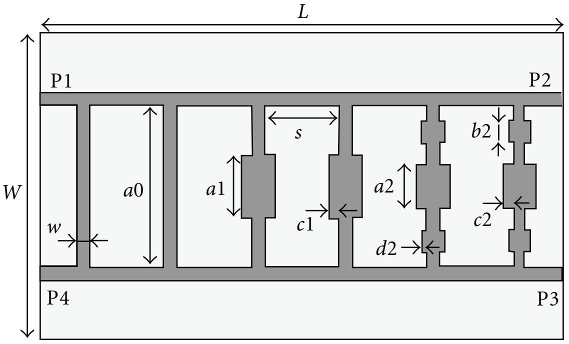

FIGURE 1: Profile of the UWB microstrip branch line coupler which consists of 2 × ordinary, 2 × first-order, and 2 × second-order Minkowski fractal branches.

TABLE 1: Topology and widebanding techniques comparison between 3 dB couplers and power dividers.

Reference number	Transmission line	UWB technique
[1]	Microstrip	Wideband stub matching
[2]	Microstrip	Wideband stub matching
[3]	CPW	Multistage Wilkinson
[4]	Microstrip	Multistage Wilkinson
[5]	Slot line	Multistage T-junctions
[6]	Microstrip	Multilayer substrate
[7]	Parallel strip lines	Multilayer substrate
[8]	Slot line	Multilayer substrate
This work	Microstrip	Fractal deformation

exploits broadside coupling via a multilayer microstrip slot configuration. The design method is based on conformal mapping techniques.

Two other UWB multilayer power dividers are presented in [7, 8]. In [7], a low-loss transition from a coaxial transmission line to a double-sided parallel-strip line is presented. On the other hand, a slot line topology with bandpass filtering is used in [8].

The UWB techniques in the references are compared together in Table 1. Most of these works are using microstrip lines and a few others use other alternatives. According to author's survey, usage of fractal geometries is not reported in branch line coupler designs, so far.

Fractal deformation in design and fabrication of an UWB branch line coupler will be demonstrated in the next sections. The Minkowski fractal will be used to redesign an ordinary 3 dB coupler and broaden its bandwidth. The coupler dimensions are optimized and the final tuned structure is fabricated. The measured and analyzed results will be presented and compared.

2. Coupler Design and Theory

Fractals are non-Euclidean geometries with some amazing behaviors and specifications. These geometries have been used in articles to achieve multiband radiation, band width broadening, and size reduction [9]. These benefits are actually resulting from curvature's self-similarity, which means these geometries represent a certainly finite area which is bounded in a theoretically infinite line.

TABLE 2: Proposed coupler dimensions [mm].

L	W	w	s	$a0$	$a1$	$c1,2$	$a2$	$b2$	$d2$
45	30	1.1	6.4	13.9	5.4	0.9	3.7	1.9	0.5

The Minkowski fractal is used in this paper to broaden the bandwidth and shrink the size of a branch line coupler. The UWB coupler profile is shown in Figure 1. This coupler possesses four ports where the input power at P1 splits equally between output ports P2 and P3. The 4th port is isolated and terminated using a matched load.

This coupler has 6 branches of parallel lines. Two of them are conventional straight lines and the remaining 4 branches have Minkowski fractals of 1st and 2nd orders. When fractal order approaches to infinity, the segment length approaches to zero and the circumference grows boundlessly. Meanwhile, the area still remains finite.

This coupler is mounted on TMM13 Rogers substrate with dielectric constant of 12.80, dielectric loss tangent of 0.002, and substrate thickness of 1.27 mm. Coupler dimensions are presented in Table 2. These dimensions are initially set to the values of a conventional branch line coupler and then tuned through a simple optimization procedure in ANSOFT HFSS 13.0.

The well-known quasi-Newton optimization method is selected with 500 iterations. Except for L, W, w, s, and a0; all other variables in Table 2 are defined as optimization variables. The goal is set to gain minimum inbound and maximum outbound return losses and also to achieve 3 dB insertion loss.

As can be seen in Figure 1, in two 2nd-order branch lines, each straight segment of the 1st order should be replaced with order one itself (to enforce self-similarity). This means that the central big square ought to have small squares protruding from each side, while it has not!

The reason is laid beneath optimization. After optimization process, the area and size of these outgrowths get smaller than realizable margins, and therefore omitted from the design.

According to the uniplanar and single-layer structure of the coupler, it has very easy fabrication process. Besides, based on the optimized fractal geometry of the coupler, it owns a compact size and broad bandwidth. These features of the coupler will be studied in the next section.

3. Results and Discussion

Hereby some terms have to be suggested for easier understanding of the text. Similar to Figure 1, a conventional branchline coupler consists of 4 ports and 6 branches of straight lines. If someone replaces the 6 ordinary branches with first-order Minkowski fractals, a 1st-order fractal couplerwill be achieved.

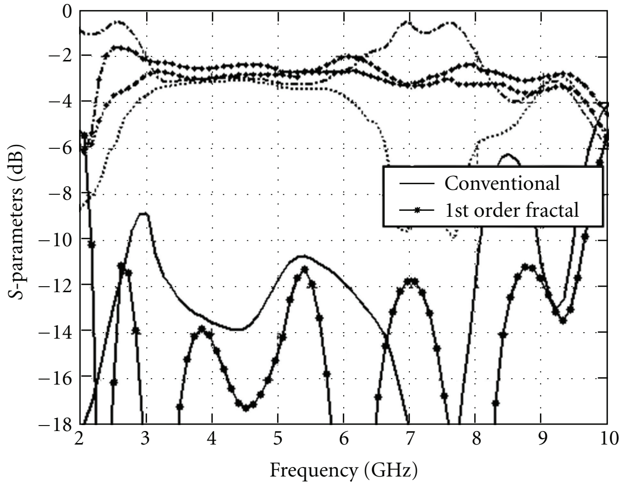

FIGURE 2: Scattering S11 (—), S21 (−·), and S31 (· · ·) parameters of the conventional branch line coupler and 1st-order Minkowski branch line coupler.

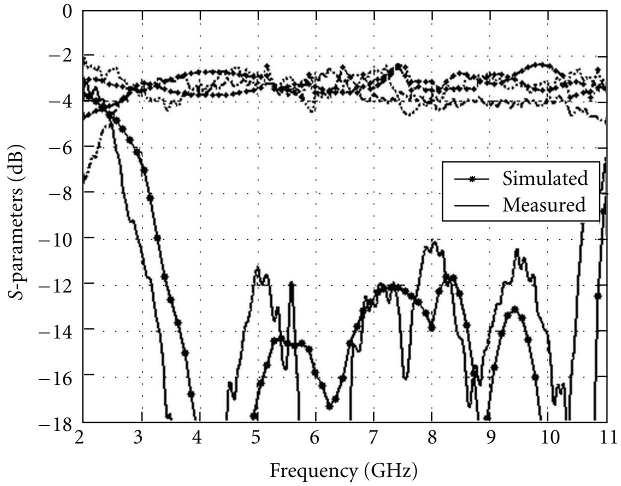

FIGURE 3: Simulated and measured Scattering S11 (—), S21 (−·), and S31 (· · ·) parameters of the UWB Minkowski branch line coupler.

In Figure 2, scattering parameters of the conventional branch line coupler has been compared with 1st-order fractal. The operating 3 dB frequency range of the conventional coupler is 3.2–6.2 GHz. This bandwidth extended to 2.6–9.5 GHz by using 1st-order fractal.

As a consequence of Figure 2, one may think of adding extra orders of the same fractal lines to extend the bandwidth. As shown exactly in Figure 1, by adding two 2nd-order lines to the conventional and 1st-order fractal branches, the operating frequency range of the coupler would expand enough to cover the UWB necessity. This property is investigated in Figure 3 where the simulation and measurement results are compared and shown a good agreement.

According to Figure 4, the phase difference at the output ports P2 and P3 remains 180 degree over the entire frequency range. Adding extra orders of the fractals has no major effect on the results and could make the fabrication process more risky and challenging.

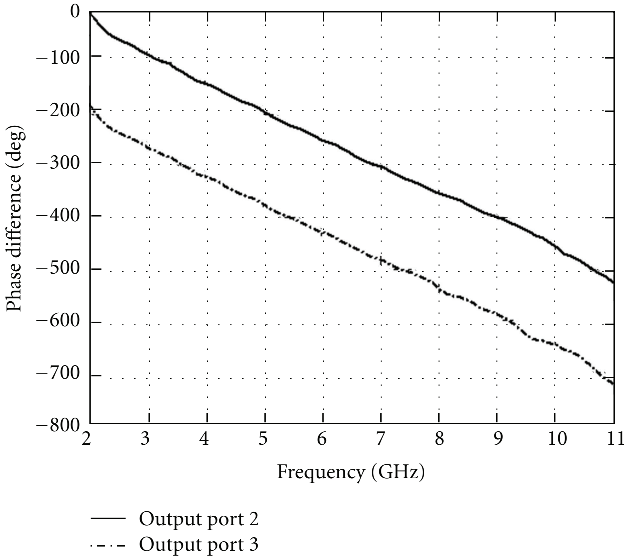

FIGURE 4: Measured output phase difference of the UWB Minkowski branch line coupler.

TABLE 3: Frequency and size comparison between 3 dB couplers and power dividers.

Reference Number	Frequency Range [GHz]	Size [mm × mm]	Size (Electrical)
[1]	3.1–10.6	40 × 50	$0.9\lambda \times 1.1\lambda$
[2]	3.1–10.6	35 × 50	$0.8\lambda \times 1.1\lambda$
[5]	3.1–10.6	40 × 50	$0.9\lambda \times 1.1\lambda$
[6]	3.1–10.6	Two × 20 × 30	Two × $0.45\lambda \times 0.7\lambda$
[7]	3.1–10.6	Two × 20 × 30	Two × $0.45\lambda \times 0.7\lambda$
This work	3.1–10.6	30 × 45	$0.7\lambda \times 1.0\lambda$

Electrical and mechanical size of some 3 dB couplers and power dividers are compared in Table 3. All these references cover the UWB frequency range and this work has the smallest size and area.

The fabricated uniplanar coupler profile is shown in Figure 5. This optimized coupler has the overall size of 30 × 45 mm^2 with 110% fractional bandwidth. The 4th port of this coupler has to be terminated to a matched load. This coupler shows 180° phase difference between output ports P2 and P3 with more than 10 dB isolation between them.

4. Conclusion

A 3 dB and 180° fractal branch line coupler is designed, optimized, and fabricated. The Minkowski fractal geometry is used to make a small and single-layer microstrip pattern with overall size of 30 × 45 mm^2. This branch line coupler covers the ultrawideband frequency range with 110% fractional bandwidth. This optimized UWB coupler is fabricated and its insertion loss, return loss, and the output phase difference

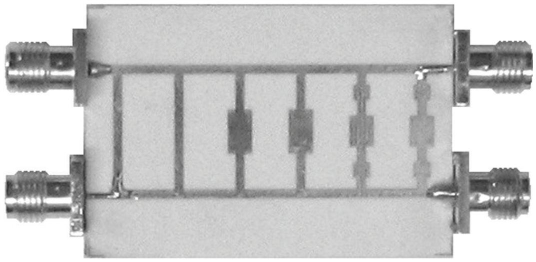

Figure 5: The fabricated profile of the UWB Minkowski branch line coupler.

have been measured, which showed a good agreement with the simulation results.

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