Harmonic Suppressed Miniaturized Koch Hybrid Coupler for IEEE802.11b/g Wireless Applications Using Circular Defected Ground Structure

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Abstract—A new 180° harmonic suppressed miniaturized Koch hybrid coupler is proposed using circular Defected Ground Structures (DGS). In order to validate the proposed design, circular DGS Koch hybrid coupler is fabricated and measured using Microstrip transmission line at operating frequency of 2.44GHz. The circular DGS Koch hybrid coupler measured results are compared with those of a conventional rat-race hybrid coupler. The measured results verify the 177.83° phase difference between two output ports. Also it has effectively suppressed the 3rd order harmonics of operating frequency by adding circular DGS on the backside metallic plate of Koch hybrid coupler. By embedding the circular DGS section, it is observed that the resonant frequency of the Koch hybrid coupler is significantly lowered, which can lead to a large amount of size reduction with harmonic suppression. Measurements of fabricated coupler prototype are in good agreement with simulation results. This circular DGS Koch hybrid coupler can be used for IEEE802.11b/g wireless applications.


I. INTRODUCTION

Hybrid couplers are key components in the design of microwave devices such as power amplifiers, mixers, and antenna systems due to their simplicity, power dividing distribution capacity, and a high isolation between two output ports[1]-[3]. The 180° hybrid coupler is usually implemented using a rat-race coupler. This hybrid coupler topology has simple designs and consequently, they are easily realized using standard printed circuit board fabrication process.

In, wireless communication systems usually require smaller device size in order to meet circuit miniaturization and cost reduction. However, in the low microwave frequency range, even the physically small size of a conventional hybrid coupler is still too large for some applications. Therefore the attempts are continually being made to reduce its size [4]-[7]. The 180° hybrid couplers are used in RF and microwave transmitting and receiving systems to divide or combine signals. Furthermore, to provide enough power, the 180° hybrid couplers are incorporated with several nonlinear amplifiers. Since the couplers are generally designed based on the electrical length of a desired fundamental signal; higher order harmonic signals from the nonlinear devices appear at the output load. Due to the nature of such conventional hybrids, they do not suppress the higher order harmonics. The radiation of harmonics generated by the nonlinear rectifying circuits has been identified as a potential problem for microwave energy transmitting and receiving systems. These harmonics could radiate freely into the surrounding environment at significant power levels to interfere with communications or harm the immediate inhabitants [8]-[10]. To suppress the unwanted harmonic power, either additional harmonic tuning circuit parts or external filters have to be inserted into the circuit. Generally low pass filter is placed for harmonic suppression. Otherwise; the coupler suffers from the presence of spurious pass-band at harmonics of the operating frequency. But this solution increases the complexity of circuit, and the insertion loss [11]. Recently in order to suppress the harmonic resonance, Split Ring Resonators (SRR), Complimentary Split Ring Resonators (CSRR), Photonic Band-Gap (PBG), Defected Ground
Structure (DGS) techniques are used in microwave circuits [12]. Recently research efforts have been made to reshape the circular hybrid ring coupler so as to reduce the occupied surface area while keeping the performance unchanged with harmonic suppression using DGS [13]-[15]. The proposed hybrid coupler may achieve the goal of small size and deep suppression of the harmonic signal, thus it may find applications in IEEE 802.11b/g WLAN, and Bluetooth applications. In this paper, a novel circular DGS technique is proposed to realize a harmonic suppressed miniaturized DGS Koch hybrid coupler. This paper presents the features of hybrid couplers, Koch fractal curves, DGS technique, design parameters and relevant equations for the circular DGS Koch hybrid coupler. To validate this idea the proposed structure is fabricated, tested and its performance is compared with a conventional hybrid coupler.

II. RAT-RACE HYBRID COUPLER

The conventional rat-race 180° hybrid coupler is a four port network as shown in figure.1. The total perimeter length of the ring equals 1.5λ at the operating frequency. To ensure matching at all ports, the characteristic impedance of the ring should be $\sqrt{2}$ times the characteristic impedance of the ports. In addition to provide the 180° phase shift between the coupled ports (2 and 4), the ports are located such that the distance between ports 1 and 2, 2 and 3 and 3 and 4 equals $\lambda/4$. The distance between port 1 and 4 equals $3\lambda/4$. The port enabling the out-of-phase signal division is called the $\Delta$-port while the one providing the in-phase signal division is named the $\Sigma$-port. The property of the ideal 180° hybrid coupler is that all four ports are perfectly matched [16].

![Figure 1. Conventional rat-race hybrid coupler](image)

III. MINIATURATION

**Koch Fractals:** In 1975, Mandelbrot introduced the word “fractal” describing a new geometry counter to the Euclidean geometry. This geometry was used to describe shapes having some special feature such as being nowhere differentiable. They are also self similar. Fractal geometry has also the major advantage of increasing the perimeter of the shape as the iteration increases, while still being confined in the same area. Thus mathematically the periphery can become arbitrary large, while the area is still finite. Recently, fractal geometries, such as Koch curve, Sierpinski gasket, Cantor dust and Hilbert curves, have been widely used to reduce the size of electromagnetic devices. These fractal shapes have two unique properties, such as space filling property and self similarity property. A fractal shape can be filled in a limited area as the order increases and occupies the same area regardless of the order. This is due to the space filling property. By self similar property, a portion of the fractal geometry always has the same shape as that of entire structure. The space filling property is useful to miniaturize physical dimensions of devices [17]. Among them Koch fractal geometries have the major advantage of increasing the perimeter of the shape as the iteration increases, while still being confined in the same area. In this paper Koch fractal structures are used to construct miniaturized Koch hybrid coupler. The relationship between the area and perimeter for the proposed Koch curves are given below. In this method, one begins with the specified initiator and a generator is applied repeatedly in a lower scale to form the fractals. In figure 2, for example $a_0$ is the initiator length and $K_n$ is the generator. Koch Fractal Curve Construction:

1. Equation (1) describes the adhoc Iterative Function System (IFS) algorithm, which is used to obtain the various Koch curves.

   $b = a_2/a_0$  

   (1)

2. And other parameters satisfy the equations $a_{12}=a_{11}=a_{13}$ as shown in figure 2. The typical square patch 1st, 2nd, 3rd iteration Koch fractal patches are displayed in figure 3. The initiator length $a_0$ corresponds to the $\lambda_2/4$ length [18]-[26]. In order to construct the generator, $n$ arbitrary transformations $K_{n}, K_1, K_2, ..., K_{n+1}$ can be applied successfully using the following equations (2) and (3)

   $K_{n+1} = a_0 (K_n) = a_0 U_{a_0} K(n)$  

   (2)  

   where $p=1, 2, 3, ..., n$;
K_{n+1} = a_n(K_n)Ua_{n-2}(K_n) \ldots Ua_{np}(K_n) \quad (3)

Koch fractal with iteration factor 0.25 is chosen to design a Koch hybrid coupler. Figure (3) shows the geometrical properties of these fractals.

Figure 2. Initiator and Generator

Figure.3 square patch 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd} Koch fractal patches

IV. HARMONIC SUPPRESSION

DGS: A DGS is usually realized by etching a specific pattern on the ground planes of microstrip lines. Any defect etched in the ground plane of the microstrip line disturbs its current distribution and can give rise to increasing effective capacitance and inductance. It produces band rejection in certain frequency bands. A variety of slot geometry etched in the microstrip line ground plane has been reported in the literature, it has been used to realize various passive and active compact structures and to suppress the harmonics. In these structures, well-defined shapes are etched at the back metal. These structures provide rejection band in some frequency range due to increasing the effective inductance of a transmission line. This rejection characteristic of DGS is available to many circuits such as power amplifier module, planar antennas, power divider, coupler and filters. The proposed circular DGS circuit, which is located on the ground metallic plane as shown in figure 4. It can be seen that employing the proposed circular DGS increases the series inductance to the microstrip line. This effective series inductance introduces the cutoff characteristic at a certain frequency. As the etched area of the circular DGS is increased the effective series inductance gives rise to a lower cutoff frequency. There are attenuation poles on the etched circular DGS. These attenuation poles can be explained by parallel capacitance with the series inductance. This capacitance depends on the etched gap below the conductor line. Thus, the equivalent circuit of the proposed etched circular DGS can be expressed as parallel LC circuit as shown in figure 5. The capacitance values are identical for all cases due to the identical gap distance. As the series inductance is increased the resonance frequency of the equivalent parallel LC circuit, which is the attenuation pole locations and the cutoff frequency becomes lower.

Figure 4. Circular DGS element

The capacitance $C_p$ in picofarads and the inductance $L_p$ in nanohenrys are computed by

$$C_p = \frac{3f_c}{\pi(f_c^2 - f_0^2)} \text{ pF} \quad (4)$$

$$L_p = \frac{280}{C_p(f_c^2 - f_0^2)} \text{ nH} \quad (5)$$

Where $f_c$, in gigahertz, is the cutoff frequency of the band reject and $f_0$, in gigahertz, is its pole frequency. We have selected the following parameters to characterize the band stop performance of the circular DGS slots as shown in figure 4.

1. Linear dimension of a slot (a)
2. Area of a slot head (d)
3. Relative control of $f_c$ and $f_0$ by changing the dimension of a slots
4. Sharpness factor $f_c/f_0$
The slot-head area basically controls the inductance whereas; the width of connecting rectangular slot controls the capacitance [27]-[34].

V. FABRICATION

**Design:** Koch fractal curves and DGS have been used to realize a harmonic suppressed miniaturized circular DGS Koch hybrid coupler. The design parameters of the circular DGS Koch hybrid couplers are shown in Table I. Koch fractal ring line width is same as that of the conventional rat-race coupler ring line width with $\sqrt{2} \ Z_o$ impedance at operating frequency. All the design parameters are synthesized using Agilent ADS Line calc, optimized using ADS2002C and Koch curve design parameters are calculated by using equation (1-2) as shown in Table I. Triangular DGS dimensions are $d=3.044\text{mm}$, $s=3.044\text{mm}$, $a=4.245\text{mm}$ at stop band frequency are calculated and optimized using equation (4)-(5).

**Fabrication:** The proposed coupler is implemented on a FR4 substrate with 1.6mm substrate thickness for operating frequency 2.44GHz. Size of the fabricated circular DGS Koch hybrid coupler and conventional hybrid coupler were compared as shown in figure .6 and figure .7.

![Figure 6: Fabricated circular DGS Koch hybrid coupler front side](image1)

![Figure 7: Fabricated circular DGS Koch hybrid coupler back side](image2)

VI. RESULTS AND DISCUSSION

The 180° circular DGS Koch hybrid coupler and conventional hybrid coupler are simulated using Agilent ADS2002C. A prototype of both couplers were fabricated and S parameter measurements were carried out using Agilent N5230A PNA series Network Analyzer. Table II shows the overall performance of the conventional hybrid coupler and proposed coupler. Simulated and measured results are shown in Fig 8 to Fig 9. Measured S parameter results are agreed well with simulated results. Conventional hybrid coupler and circular DGS Koch hybrid coupler has 2.83° and -3.5601° phase error. The very sharp notch performance has been found in 3rd order harmonics of operating frequency 2.44GHz.

![Table I: Design Parameters](image3)

![Table II: Simulated and Measured Parameters](image4)
Figure 8a: Return Loss S11

Figure 8b: Coupling Loss S12

Figure 8c: Isolation Loss S13

Figure 8d: Coupling Loss S14

Figure 9a: Phase response S12

Figure 9b: Phase response S14
VII. CONCLUSION

This paper has demonstrated the harmonic suppressed miniaturized circular DGS Koch hybrid couplers. This DGS Koch hybrid coupler can be utilized for IEEE 802.11b/g wireless applications demanding band rejection and small geometry. The performance of the proposed hybrid coupler is as good as that of conventional hybrid couplers. The amount of size reduction depends on the choice of Koch iterative function. Further size reduction is possible through the use of higher iterations. However, this will result in a reduced segment size, which will not be compatible with the standard PCB fabrication process. Other fractal curves can be investigated for further size reduction for system-on-package integration.

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