A Rectangular Patch Antenna with Wideband High Order Harmonic Suppression Using Compact Defected Microstrip Structure

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Abstract— High order harmonic may affect antenna performance, reduce antenna efficiency and cause electromagnetic interference. So suppression of the harmonic has been a focus issue in the field of antenna design. It is demonstrated that the photonic band gap (PBG) structure and defect ground structure (DGS) provide an effective way for suppressing high order harmonics of antenna. In this paper, a novel antenna with wideband high order harmonic is presented by using the proposed complementary opening defected microstrip structure (CODMS). The proposed structure cell with great advantages in the miniaturization of the antenna contains two fundamental resonant frequencies which can be tuned by adjusting the geometry parameters. First, the influence of CODMS cell parameters on the band-stop is examined in order to obtain design rule for the harmonic suppression. Second, two CODMS cells with different size in a novel configuration is developed in order to control harmonics of the rectangular patch microstrip antenna with the fundamental frequency at 1.5 GHz. By elaborately designing the structure parameters, four band-stops are achieved which match the four high order harmonics of the antenna well. Then, the patch antennas with the proposed CODMS are implemented with the conventional patch antenna without the CODMS as a reference. The simulated results show that the reflection coefficient from the second to the fourth harmonics has been effectively suppressed over 3 dB without affecting the fundamental frequency and the maximum inhibition effect appears at the second harmonic reaching 9.2 dB. The co-polarized and cross-polarized fields at the fundamental frequency of the presented antenna have little discrepancy with the reference antenna while the radiation pattern at the high order harmonics is suppressed about 15 dB in both E-plane and H-plane. Thus, the presented antenna has superiority in suppressing wideband high-order harmonics with compact size, which also maintains the integrity of the ground plane, making it easier to integrate with microwave circuit for wireless applications.

1. INTRODUCTION

With the development of antenna technology, one of the focusing issues nowadays is integrating antennas and filters. Suppressing the wideband high order harmonic attracts more and more researchers' attention. Integrating filter at input front end of antenna is the common method to suppress high order harmonics [1–3]; however, it may increase complexity of the circuit and the matching network design. Further, scholars put forward the integrated design of filter and antenna to suppress harmonics, and found that PBG and DGS could be used to suppress the high order harmonics by employing the inhibitory effect of the plane artificial electromagnetic structure. In 1999, Horri and Tsutsumi introduced two-dimensional PBG in the ground to suppress the harmonics of single microstrip patch antenna [2]. In [7], a defected ground structure (DGS) with highly compact design of partial ring was proposed, and the high order modes from TM_{20} to the TM_{40} mode had been controlled. Z. Ma et al. took a monopole antenna fed by coplanar waveguide for example and used a miniaturized resonant structure cell and a U slot to suppress the antenna at the second and third harmonics [8]. A wideband harmonic suppression antenna was obtained in [9, 10] by skillfully combining the U-shaped groove and coupling gaps. The challenge now is how to achieve high order harmonic suppression in a very small physical space.

In this paper, a novel method with two different CODMS cells etched parallel on the feed line is proposed to suppress the wideband high order harmonics which has advantages in maintaining the integrity of the ground floor, promoting integration and decreasing interference. Compared with other shaped DMS cells at the same resonant frequency, the CODMS cell proposed in this paper has occupied the smallest area which has great advantageous in the miniaturization of the antenna. In addition, the influence of compact CODMS parameters on stop-band characteristics in order to optimize parameters match the wideband harmonic of the antenna has been studied. Finally, by properly designing the structure parameters, a novel combination of two different CODMS owing four band-stops within 6 GHz has been achieved, which agrees with the wideband high order harmonics of the antenna. Then, the antenna with and without two CODMS has been simulated and compared; the reflection coefficient from the second to the fourth harmonics has been effectively suppressed to over 3 dB without affecting the fundamental frequency and the maximum inhibition effect appears at the second harmonic reaching 9.2 dB. The co-polarized and cross-polarized fields at the fundamental frequency of the presented antenna have little discrepancy with the reference antenna while the radiation pattern at the high order harmonics is suppressed about 15 dB in both E-plane and H-plane.

2. COMPLEMENTARY OPENING DEFECTED MICROSTRIP STRUCTURE

The CODMS cell is composed of two rectangular ring slots with opposite direction of short side opening. The layout of the proposed CODMS cell is showed in Fig. 1(a), where $a1$ is the length of external rectangular slot length; $a2$ is width of the external rectangular slot; w is the width of slot; $x1$ is the distance of the inner and outer rectangular slot. The CODMS cell is simulated by the full-wave solver Ansoft HFSS. Fig. 2(a) shows the simulated S-parameters of the cell, where the center frequency of the two band tops are located at 2.9 GHz and 4.5 GHz with the 3 dB fractional bandwidths (FBW) are 6.3% and 2.3% respectively.

Figure 1. Layout of the CODMS cell and proposed two cells structure (a) parameters of one cell: $a1 = 15$ mm, $a2 = 1.8$ mm, $a3 = 0.3$ mm, $w = 0.2$ mm. $x1 = 0.25$ mm, (b) parameters of below cell: $a1 = 15$ mm, $a2 = 1.8$ mm, $a3 = 0.3$ mm, $w = 0.2$ mm, $x1 = 0.25$ mm; parameters of top cell: $a1 = 11.9$, $a2 = 2$, $a3 = 0.3$ mm, $w = 0.2$ mm, $x1 = 0.2$ mm.

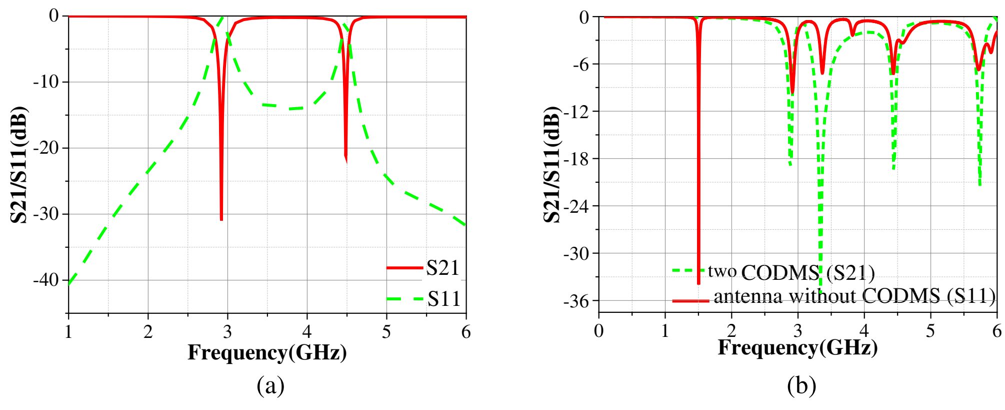

Figure 2. S-parameters. (a) Return loss (S_{11}) and insertion loss (S_{21}) of the CODMS cell. (b) The S_{21} of the two CODMS cells and S_{11} of antenna without CODMS.

The influence of the structure parameters on the first and second resonant frequency is investigated to obtain design rule for the subsequent harmonic suppression of antenna.

As can been seen in Fig. 3(a), when $a1$ increases, keeping other parameters unchanged, the length of slot line and the area of the cell increase, the first and second resonance frequencies reduce in Fig. 3(a).

With the increase of $a2$, keeping other parameters unchanged, the length of slot line and the area of the cell increase, first resonance frequency reduces, the second resonance frequency remains unchanged in Fig. 3(b).

Along with w increasing, keeping other parameters unchanged, the total length of the slot line hardly effects, so the resonant frequency have no obvious change in Fig. 3(c).

While $x1$ increases, coupling of the internal and external structure decreases. The first resonant frequency increases, second resonance frequency reduces in Fig. 3(d).

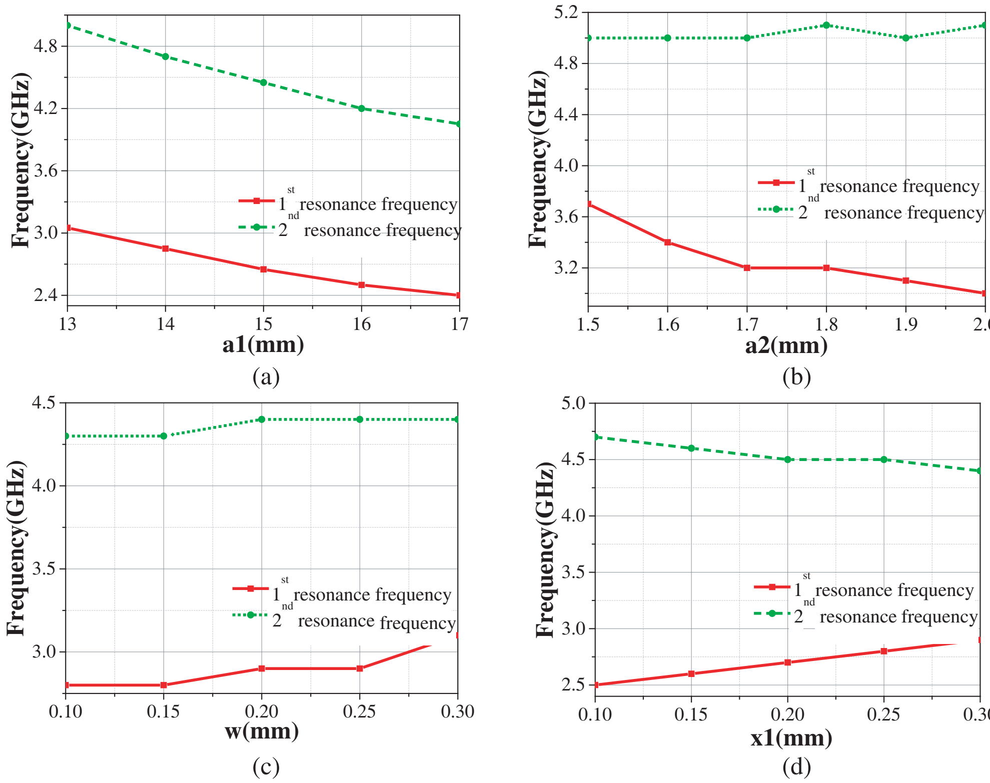

Figure 3. Influence on the resonant frequency and 3 dB FBW of the first stop-band.

Two CODMS cells in a novel configuration with different sizes are proposed. Fig. 1(b) shows the layout of the new designed combine structure and its reflection coefficient is shown in Fig. 2(b). By etching two CODMS cells parallel on the feed line, a four adjust band-stops less than 6 GHz has been obtained. This method makes full use of the band-stop characteristics of a single cell. This is effectively combination band-stops of two cells and forms four adjust band-stops with 6 GHz.

3. RECTANGULAR PATCH ANTENNA WITH WIDEBAND HIGH ORDER HARMONICS SUPPRESSION

A conventional rectangular patch microstrip antenna as the reference antenna is implemented in Fig. 4(a) and its simulated reflection coefficient is shown in Fig. 2(b). The substrate used is Arlon AD255A(tm) (relative permittivity $\varepsilon_r = 2.55$ and thickness $h = 1.5$ mm). The width of the microstrip line keeps 4.2 mm, the characteristic impedance is 50 ohm, the width of the cell structure is 2 mm, and the width of the slot is 0.2 mm. The slot plays the role of impedance matching. The fundamental frequency of the antenna is 1.5 GHz, and within the 6 GHz there are 4 higher order harmonic modes.

To control these harmonics the presented two CODMS cells structure is used to control the harmonics within 6 GHz of the conventional antenna over such a wide range of frequency. The band-stop effect of the CODMS cell is fully utilized. For the reference antenna, four harmonics appears respectively at 2.9 GHz, 3.3 GHz, 4.4 GHz and 5.7 GHz. Combination of two cells to form the four band stops is an effective method. The novel structure design composed of two CODMS cells with different sizes are also presented in Fig. 1(b). According to the previous study of the influence of the structure parameters on the resonant frequency and -3 dB FBW, the band-stops of the structures are adjusted to suppress the four harmonics. In the designed structure, one cell forms the stop band corresponding high order harmonic of antenna at 2.9 GHz and 4.4 GHz and the other cell forms the stop band corresponding high order harmonic of antenna at 3.3 GHz and

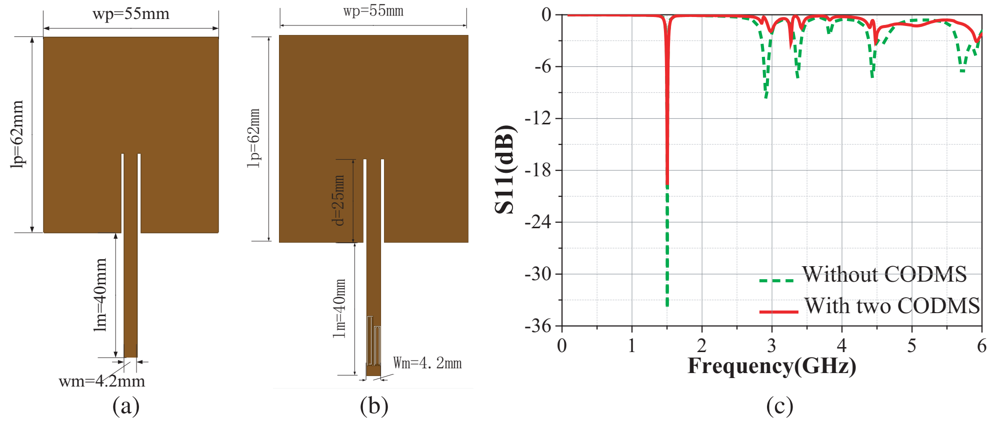

Figure 4. Layout and S_{11} of original antenna without and with double CODMS.

5.7 GHz. The designed structure forms a fourth stop band which agrees with the higher order harmonics of the antenna.

Figure 4 shows the configuration of the conventional antenna loaded by the designed structure and return loss of both the proposed and reference antennas. Simulated results are shown for comparison in Fig. 4(c). The prohibitive effect from 2 GHz to 6 GHz is superior to 3 dB, and the best suppression occurs at the second harmonic reaching 9.2 dB. This achieves control of the wideband high order harmonics up to the fourth harmonic of the antenna basing on maintaining the fundamental frequency. Radiations at the high order harmonics frequency should be reduced while radiations at the fundamental frequency should be effected hardly.

Following researches are aimed to study the radiated patterns at fundamental frequency and

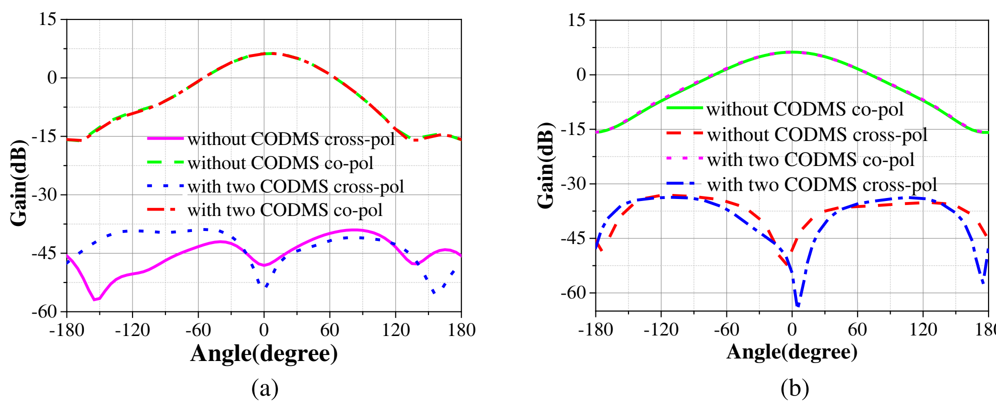

Figure 5. Simulated radiation patterns at 1.5 GHz with and without DMS. (a) E-plane (b) H-plane.

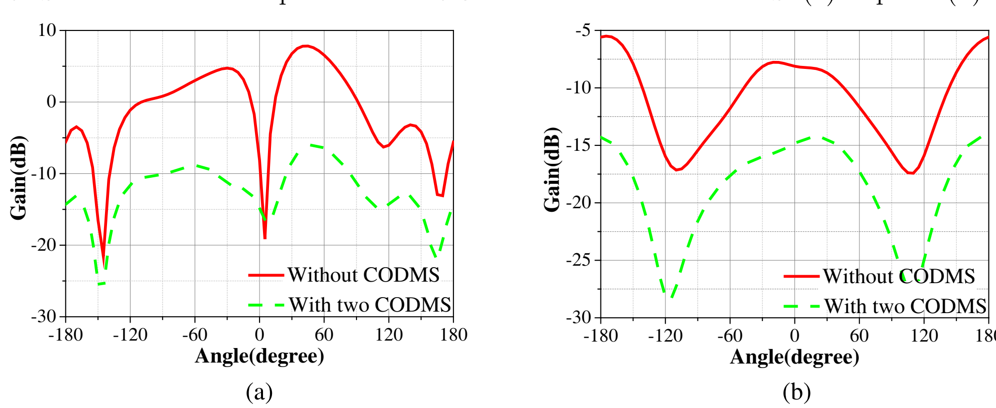

Figure 6. Simulated radiation patterns with and without CODMS at the second harmonic (2.9 GHz). (a) $\varphi = 0^\circ$ E-plane, (b) $\varphi = 90^\circ$ H-plane.

high order harmonics frequency. Fig. 5 presents simulated radiation characteristics at fundamental frequency (1.5 GHz) of the proposed antenna and reference antenna for both E-plane ($\varphi = 0^\circ$) and H-plane ($\varphi = 90^\circ$). It can be seen that the co-polarized radiation of the proposed antenna is hardly effected, which meets the requirements of suppressing harmonics. Suppression of high order harmonics is maintaining radiation of the fundamental frequency and weakening radiation of harmonic. Simulation data shows the effectiveness of this method. Simulated peak gain of the co-polarized both E-plane and H-plane are obtained near 6 dB.

Figure 6 depicts the E-plane and H-plane at the second harmonics 2.9 GHz. In H-plane, about 15 dB suppression is obtained, while the maximum inhibitory effect in E-plane is 17 dB. According to these simulation structures, it is clear that the new design is effective to suppress the wideband high order harmonic of the patch microstrip antenna.

4. CONCLUSION

Suppressing the wideband high order harmonic up to the fourth harmonic, with miniaturization characteristic, is proposed by the novel combination of two compact CODMS structures. The patch antennas with and without the compact CODMS have been simulated and compared. Simulation results show that the inhibitory effect is superior to 3 dB, and the best suppression achieves 9.2 dB. Radiated fields at harmonics are suppressed near 15 dB considering both E-plane and H-plane, while co-polarized and cross-polarized fields at the fundamental frequency show no significant influence. The correctness of the method has been verified, and it is clear that the new design is effective to suppress the wideband high order harmonic of the microstrip patch antenna.

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REFERENCES

1. Horri, Y. and M. Tsutsumi, "Harmonic control by photonic bandgap on microstrip patch antenna," *IEEE Microwave Guided Lett.*, Vol. 9, 13–15, Jan. 1999.
2. Liu, H., Z. Li, X. Sun, and J. Mao, "Harmonic suppression with photonic bandgap and defected ground structure for a microstrip patch antenna," *IEEE Microw. Compon. Lett.*, Vol. 15, No. 2, 55–56, Feb. 2005.
3. Ren, Y. and K. Chang, "5.8-GHz circularly polarized dual-diode rectenna and rectenna array for microwave power transmission," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 4, 1495–1502, Apr. 2006.
4. Kobori, T. and H. Arai, "Harmonics suppression for circular microstrip antenna with slits and open stubs," *Department of Electrical and Computer Engineering*, Yokohama National Univ..
5. Pobanz, C. W. and T. Itoh, "A Two-dimensional retrodirective array using slot ring FET mixers," *Proc. 26th European Microwave Conference*, 217–220, Czech Republic, Sept. 1996.
6. Liu, H., Z. Li, X. Sun, and J. Mao, "Harmonic suppression with photonic band gap and defected ground structure for a microstrip patch antenna," *IEEE Microwave and Wireless Component Letters*, Vol. 15, No. 2, 55–56, 2005.
7. Biswas, S., D. Guha, and C. Kumar, "Control of higher harmonics and their radiation in microstrip antennas using compact defected ground structures," *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 6, 3349–3353, 2013.
8. Ma, Z. and G. A. E. Vandenbosch, "Wideband harmonic rejection filtenna for wireless power transfer," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 1, 371–377, 2014.
9. Sim, C., M. Chang, and B. Chen, "Microstrip-fed ring slot antenna design with wideband harmonic suppression," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 9, 4828–4832, 2014.
10. Liu, Y. W., Y. Lu, and P. Hsu, "Harmonic suppressed slot loop antenna fed by coplanar waveguide," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 1292–1295, 2014.