A Novel Harmonic Suppression Antenna with Both Compact Size and Wide Bandwidth

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Abstract **─** A novel CPW-fed harmonic suppression antenna with both compact size and wide bandwidth is proposed and investigated in this paper. The second and third harmonic frequencies are suppressed effectively with square-shaped lattices inserted in the ground plane. Furthermore, by exploiting the Vivaldi-shaped structure and two simple rectangular slots, wide bandwidth (1.86GHz) ranging from 1.9GHz to 3.76GHz is also obtained with rather compact size of 10mm × 10mm, which is much smaller than that have ever been reported before. Eventually, the measured results confirmed the simulated dates.

Index Terms **─** Compact size, harmonic suppression, PBG, Vivaldi shaped structure, wide bandwidth.

I. INTRODUCTION

The harmonic suppressed antenna (HSA), due to its great advantages such as low cost, small size, and easy integration, has become more and more attractive for various applications, such as wireless communications and microwave power transmission (MPT) [1-4]. Usually, a harmonic suppression filter will be required in those systems to avoid the harmonic influence on the overall system performance. However, it is bulky, expensive and hard to be integrated in monolithic microwave integrated (MMIC) devices. To overcome these defects, HSAs have been widely investigated these years: shorting pin [5], tuning stub [6], defected ground plane structure (DGS) [7], photonic band gap (PBG) [8], and the electromagnetic band gap structure (EBG) [9] can all suppress the harmonic effectively. Besides, considerable research efforts have been made towards the miniaturization and broadband of HSAs. In [10], by inserting symmetrical slots in the ground plane of an open-ended CPW-fed transmission line, fairly compact dimensions, 26mm × 15mm in physical size ,and $0.3\lambda_g \times 0.17\lambda_g$ (λ_g is the wavelength in the substrate at the resonant frequency) in electrical size was obtained. In [11], a broadband HSA, with a 10-dB impedance bandwidth spanning from 1.56 GHz to 2.88 GHz (1.32GHz), was achieved by exploiting PBG structures with cross-shaped lattices. However, the compact HSA suffers a quite narrow bandwidth of 200 MHz, and the broadband HSA is very limited by its rather big size of about 50mm×60mm.

In this paper, a novel harmonic suppression antenna with both compact size and wide bandwidth is presented. To suppress harmonics, PBG structures with square-shaped lattices were exploited. On the other hand, by employing the Vivaldi-shaped structure and two rectangular slots, a rather compact and small dimensions , 10mm × 10mm in physical size, and $0.1\lambda_g \times 0.1\lambda_g$ in electrical size, is achieved with a wide bandwidth of 1.86 GHz spanning from 1.9 GHz to 3.76 GHz. Eventually, the experiment results agree well with the simulated dates.

II. ANTENNA DESIGN

The existing planar microstrip antennas are mostly in symmetrical structures, especially the printed monopoles antennas [12-13]. For those symmetrical structures their half formats have all the necessary dimension features for the resonant

Submitted On: April 17, 2011
Accepted On: Dec. 18, 2011

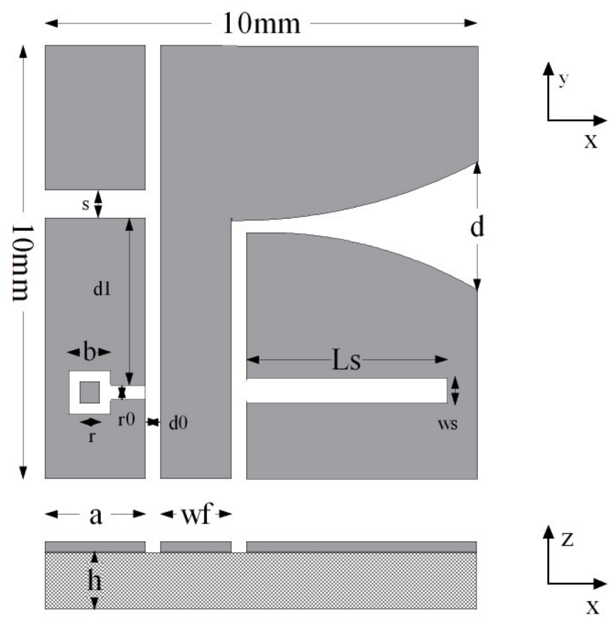

Fig. 1. Geometry of the proposed HSA.

frequencies. Therefore, it is expected that the miniaturized half structures of these symmetrical printed monopole antennas can achieve similar impedance features as the un-miniaturized full structures. Particularly, by simply exploiting its structural symmetry, 40% reduction in size was realized in [14]. Accordingly, similar but modified technology is applied to reduce the total size of the proposed harmonic suppression antenna at the beginning design, and then the PBG structure is used to suppress the harmonic frequencies.

Figure 1 shows the geometry of the proposed compact HSA with wide bandwidth. This antenna is printed on the RO4003C substrate with size of 10mm×10mm, thickness of 0.5mm, and dielectric constant of 3.38. The width of the coplanar waveguide feeding line w_f is fixed at 1.6mm and the gap d_0 is fixed at 0.1mm to achieve 50Ω characteristic impedance.

Half structures of a Vivaldi-shaped printed monopole antenna, which is formed by the index gradient curve, are exploited at first. In order to further reduce the antenna size, a rectangular ground plane with a rectangular slot was added to the left side of the coplanar waveguide feeding line. Moreover, another rectangular sot was etched in the right ground plane. On the other hand, to suppress the harmonic frequencies, PBG structures with square-shaped lattices were inserted only in the left ground plane. Particularly, the two rectangular slots, which can control the strength of coupling and guide the current distribution, are critical to the design and need to be carefully adjusted. At last, a fairly compact size and harmonic suppression as well as wide bandwidth are obtained at the same time.

III. RESULATS AND DISCUSSION

The proposed harmonic suppression antenna with both compact size and wide bandwidth are constructed, and the numerical and experimental results are presented and discussed. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. To fully understand the behavior of the antenna's structure and to determine the optimum parameters, the antenna was analyzed using the business software CST. And the prototype of the proposed antenna with optimal design, i.e. a=2mm, s=0.3mm, w_s=0.5mm, d=5mm, d_1=4.5mm, L_s=6mm, b=1mm, r_0=0.1mm, r=0.4mm, is shown in Fig. 2.


Fig. 2. Prototype of the proposed HSA.

In order to minimize the physical size of the proposed antenna, a rectangular slot is introduced into the right ground plane to alter the input impedance characteristics. As illustrated in Fig. 3, the slot can effectively lengthen the equivalent electrical length and the resonant frequency goes lower when the length of the slot L_s increases gradually.

Figure 4 exhibits the effects of the PBG on the impedance matching in comparison to the same antenna without PBG and three cases with PBG. It is found that the PBG structure successfully suppressed the second and third harmonic frequencies. Furthermore, an extra resonant frequency is excited, thus a much wider impedance bandwidth is obtained. Also, from the results shown in Fig. 4, it can be observed that the parameter *b* have only impact on the extra resonant frequency. As the parameter *b* decreases from 1.1mm to 0.9mm gradually, the second resonant frequency increases correspondingly, while the first resonant frequency almost remains still.

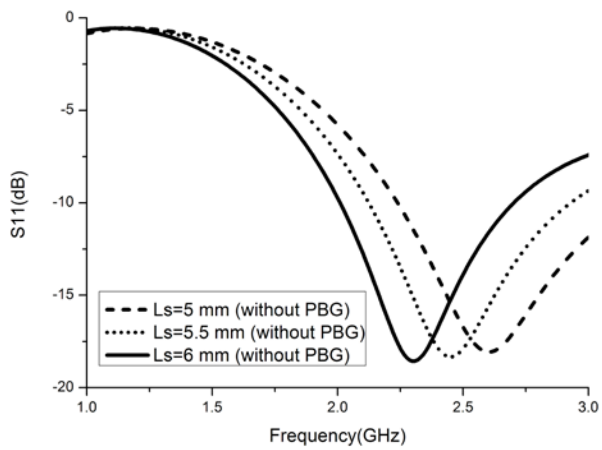

Fig. 3. Simulated S11 curves for the proposed antenna with different length of *Ls*.

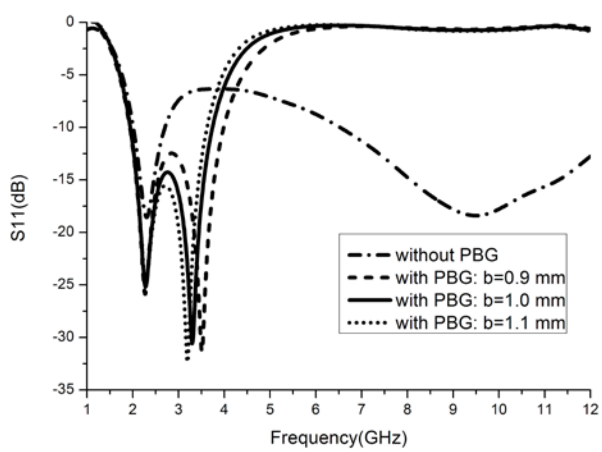

Fig. 4. Simulated S11 curves for the proposed antenna without PBG and with different PBG dimension of *b*.

Similarly, the S11 curves for various distance d_1 are plotted in Fig. 5. It can be observed that the parameter d_1 also mainly affects the second resonant frequency. And as d1 increases from 3.5mm to 4.5mm, the second resonant frequency shifts left. However, as shown in Fig. 6, the width w_s not only has impact on the second frequency but also the first one. The first resonant frequency decreases when the width w_s increases, while the second resonant frequency increases.

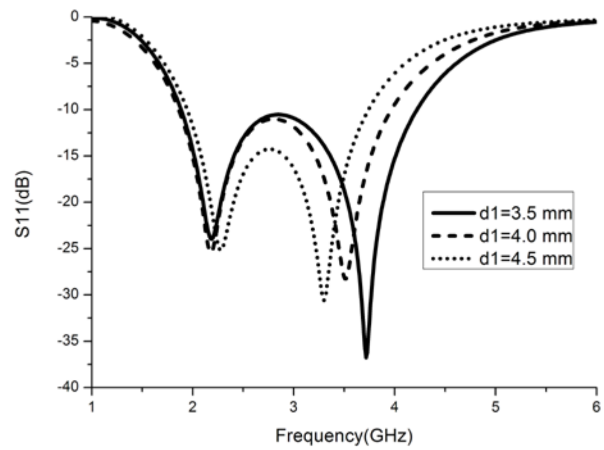

Fig. 5. Simulated S11 curves for various distance d_1.

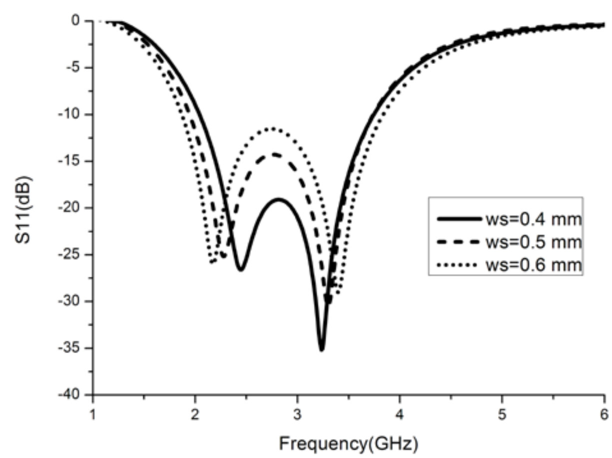

Fig. 6. Simulated S11 curves for various width w_s.

Eventually, the simulated and measured S11 of the proposed harmonic suppression antenna with optimized design are demonstrated in Fig. 7. Because FEKO is mostly used for large electrical size problems and the proposed antenna is very small, only CST, HFSS as well as IE3D were used to validate the results. Compared with the HFSS solver which is based on frequency domain, the transient solver of CST is based on time domain; thus, it is more suitable for wideband simulation cases. Therefore, the simulated results by the CST are quite similar to the measured results. Besides, the IE3D is based on the MOM algorithm, and it's more suitable for planar structures. From the results in Fig. 7, it can be seen that the three results are similar and the -10dB impedance bandwidth of the proposed HSA is ranging from 1.9GHz to 3.76GHz, which is almost the maximum bandwidth since the lowest second harmonic frequency is 3.8GHz. The experiment results validate the design with only a slight shift. Furthermore, it is also noticed that the antenna is only 10mm × 10mm in physical size and 0.11 λg × 0.11 λ_g in electrical size, which is much smaller than that have ever been reported before. Compared with the above mentioned compact HSA and the broadband HSA, this compact broadband harmonic suppression antenna proposed in this paper offers an even smaller size and broader bandwidth, e.g. about 76% and 96% reduction in size, 830% and 41% enhancement in bandwidth, respectively.

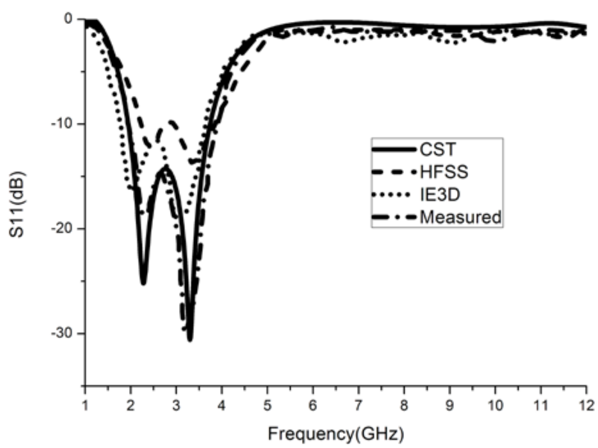

Fig. 7. The simulated and measured S11 for the proposed HSA with PBG structure.

Furthermore, as a very important aspect of a practical antenna, the efficiency of the proposed antenna is also investigated. The efficiency of the proposed HSA with PBG structure is shown in Fig. 8. And the efficiency of the reference antenna without the PBG structure is also shown for comparison. It can be observed that the reference antenna without the PBG structure is below 50% in the bandwidth since the total antenna size is rather small. Moreover, the suppression of the harmonics affects the antenna efficiency a lot. In the working band from 1.9GHz to 3.76GHz, the antenna efficiency almost remains the same. However, compared with the antenna without harmonics suppression, the antenna efficiency with harmonics suppression goes much lower in the harmonics bands.

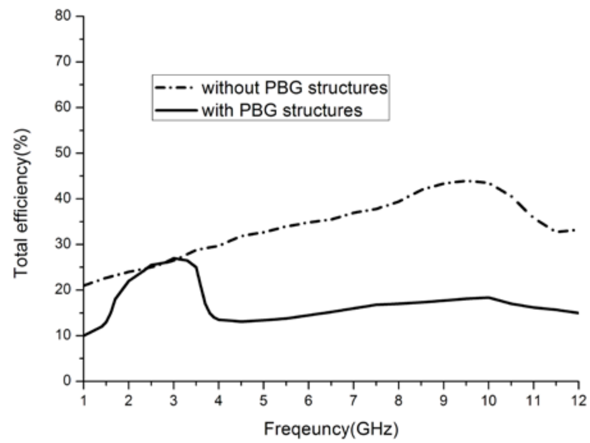

Fig. 8. The efficiency of the proposed HSA with PBG structure and the reference antenna without PBG structure.

Additionally, the radiation patterns of the proposed HSA with PBG structure and the reference antenna without PBG structure at 3GHz, 6GHz, and 9GHz are shown in Fig. 9 (a), (b), and (c), respectively. It illustrates that compared with the reference antenna, the proposed HSA could suppress the second and the third harmonics without deteriorating the fundamental radiation patterns.

IV. CONCLUSION

In this paper, a novel CPW-fed antenna with harmonic suppression is proposed and investigated. Both compact size and wide bandwidth are achieved by employing both the Vivaldi-shaped and PBG structures along with two simple rectangular slots. Particularly, it exhibits a smallest dimension up to now, 10mm × 10mm in physical size, and $0.11\lambda_g \times 0.11\lambda_g$ in electrical size, with a rather wide bandwidth spanning from 1.9 GHz to 3.76 GHz. With all these promising features, the proposed HSA is very attractive for wireless communication and microwave power transmission applications.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (No. 61172115 and No. 60872029), the High-Tech Research and Development Program of China (No. 2008AA01Z206), the Aeronautics Foundation of

China (No. 20100180003), and the Fundamental Research Funds for the Central Universities (No. ZYGX 2009J037).

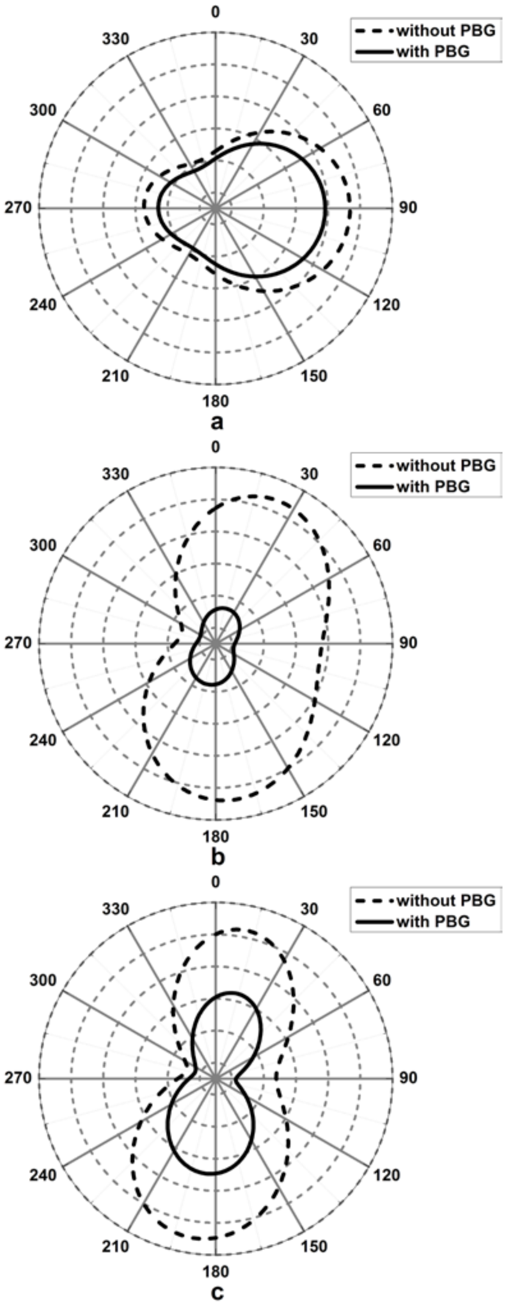

Fig. 9. The radiation patterns of the proposed HSA with PBG structure and the reference antenna without PBG structure at a) 3GHz, b) 6GHz, and c) 9GHz.

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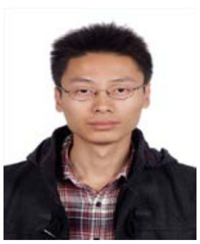

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