Compact Filtenna with Defected Ground Structure for Wireless Power Transfer Application

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***Abstract*—A compact proximity coupled high harmonic rejection filtenna is presented in this paper. The proposed structure operates in the unlicensed 2.45GHz Industrial, Scientific and Medical (ISM) band. A circular ring slot has been built-in on the ground plane parallel to circular patch, resulting in a 45% reduction area of patch element area as compared to conventional designs. Unique U-shaped slot arrangements are created on the ground plane parallel to the transmission line feed as defected ground structures (DGS) to achieve rejection of higher harmonics. Acceptable suppression of the second and third harmonics is achieved with minimum reflection coefficients of -4.1 dB and -1.8 dB respectively. The proposed design shows good potential for implementation in wireless power transfer and radio frequency energy harvesting infrastructure.**

Keywords—compact; defected ground structure; harmonic rejection antenna

I. INTRODUCTION

The harvesting of energy from ambient sources has attracted considerable contemporary research interest. One such ambient energy source with considerable potential consists of electromagnetic radiation from wireless communication infrastructure. The rapid growth of wireless communications within the past decade has resulted in ambient radiation at radio frequency (RF) becoming a largely pervasive energy source. The Ultra High Frequency (UHF) band (3 MHz – 3 GHz) is of particular interest, especially due to the extensive outdoor deployment of mobile networks, and the widespread indoor use of wireless local area networks (WLAN).

Rectennas are key components of radio frequency energy harvesting systems. Their designs are guided by considerations for conversion efficiency and device size [1]. A conventional rectenna is a combination of a patch antenna, low-pass filters, and a diode rectifier. The filter employed after the rectification stage serves to eliminate higher order resonances that result from diode non-linearities. In addition, the filter placed just after the antenna leads to improvements in the RF-to-DC conversion efficiency by facilitating the rejection of unwanted harmonics [2-3]. Unfortunately, the presence of filters generally leads to larger device form factors. Size reduction can be obtained by combining the filter and antenna in a structure known as a filtenna [4-5].

Various techniques have been proposed to filter out unwanted harmonics, and reduce patch antenna size. Techniques to ensure harmonic rejection include the use of various shapes of slots, slits, and stubs on the radiating element [6-8]. On the other hand, the feeding mechanism has implications on the size of the filtenna, with non-contact proximity feeding leading to reduced sizes. Defected ground structures (DGS) have also been shown to enable compact antenna sizes [9-10].

This paper presents a numerical design of a compact filtenna at 2.45 GHz. The filtenna is realized by introducing a filter on the ground plane, of a microstrip antenna, thereby realizing a defected ground structure (DGS). The numerical design is based on an evolutionary methodology. It begins with the design of a compact proximity microstrip antenna by adding a circular slot ring. Two unique U-shaped slots are then added near the transmission line to realize a DGS, thereby suppressing the second and third harmonics of the resonance frequency. Details of the design procedure, simulation, and optimization are presented in next section.

II. FILTENNA STRUCTURE

This section elaborates on the numerical design of the antenna and filter, combined as a filtenna. First, the compact antenna design is presented, followed by the filter design procedure. The proposed structure is designed on the inexpensive 1.6mm-thickness FR-4 board, with loss tangent of 0.019 and permittivity of 4.7. All simulations and optimization were performed using the commercially available Computer Simulation Technology (CST) Microwave Studio.

A. Compact Proximity Coupled Antenna

The microstrip patch antenna is based on a proximity-coupled-feed, non-contact coupling mechanism. This proximity coupled-feed has a sandwich layer configuration, where the transmission line is placed between antenna and ground plane, and spaced between two layer substrates. Information proposed structure is shown in Fig.1. From the fundamentals of microstrip antennas, the calculated radius of the circular patch Rp with a full ground plane is 16mm.

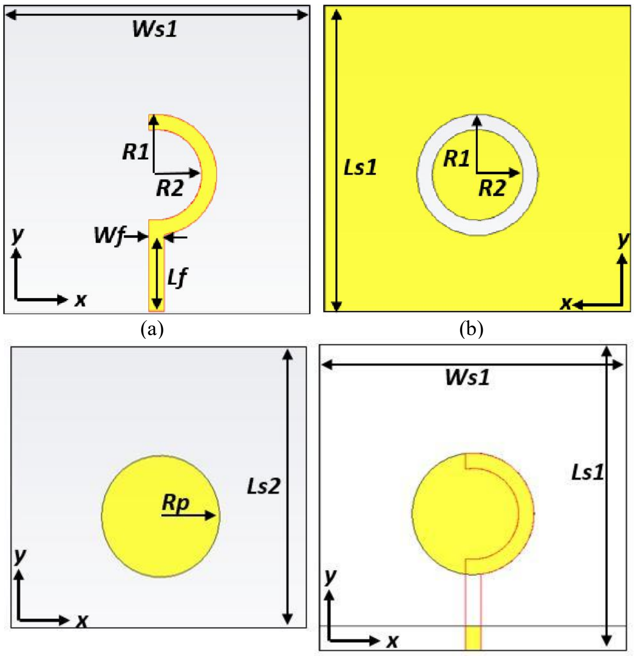
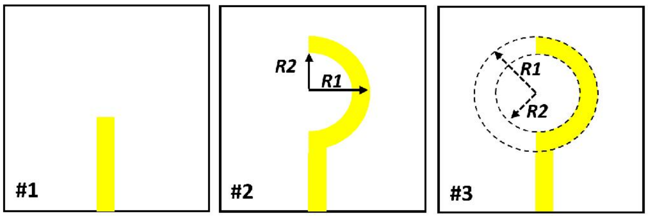


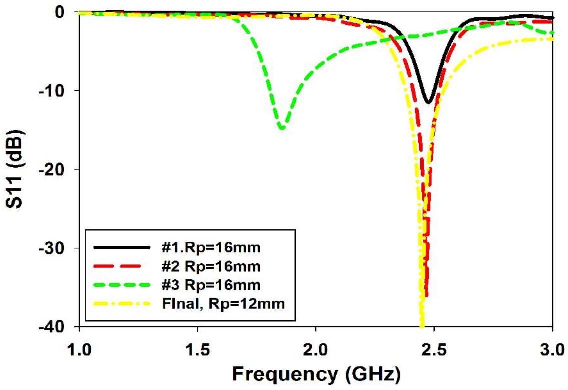
Fig. 1. Details two layer proximity coupled fed proposed compact antenna (a) Front view of bottom layer, (b) Back view of bottom layer, (c) Front view of upper layer, (d) Front view of complete structure.

Fig.2 shows the reflection coefficient results of the compact antenna evolution, starting from the conventional basic design until the proposed compact structure. A simple straight transmission line feed, with total feed length of *Lf*, was used to excite the antenna. This resulted in an initial reflection coefficient, S11, of approximately −15dB at 2.45GHz, as shown by the solid black-line. The S11 result was improved by integrating an inverted C-shape with the straight line transmission line. The realized S11 result has a minimum of −36dB at 2.45GHz, as shown by the dotted red.

Further evolution of the antenna structure was achieved by introducing a 3 mm-wide circular ring slot on the ground plane. It was placed parallel to the inverted C-shaped transmission line. With the remaining the patch size, the resonance frequency was shifted to a lower frequency, with a minimum S11 value of −17dB S11 occurring at 1.8GHz, shown with the medium dash green line in Fig.2. Consequently, to ensure the proposed antenna was excited at 2.45 GHz, the circular patch size had to be further reduced. Re-optimization of the patch radius, Rp, led to an optimal value of Rp = 12 mm. With this patch size, the minimum S11 value of −40dB was realized at 2.45 GHz, as shown by the yellow dash-dotted line.



(a)



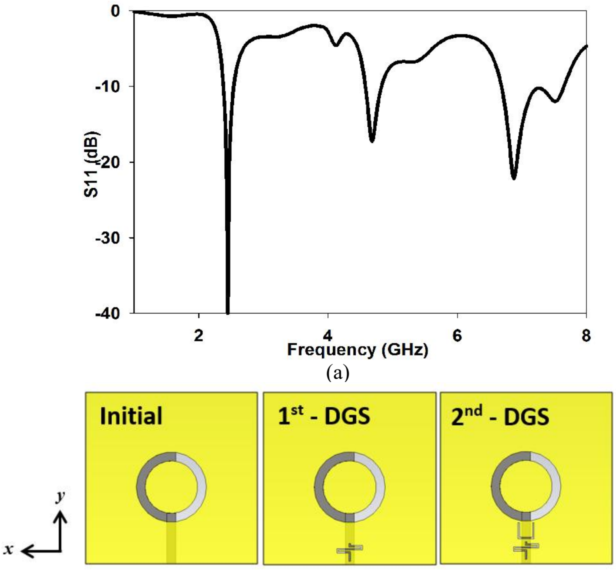
(b)

Fig. 2. Analysis of antenna compactness, (a) Front view of 1st layer Fr-4, #1; straight transmission line, #2; integrated with inverted C-shaped, #3; Circular ring slot on ground plane, (b) Reflection coefficient performance.

Consequently, this has effected an approximately 42% reduction in circular patch radiating element area compared to a conventional design. This proposed technique also give better efficiency improvement up 85% as discussed in [10].

B. Filter Design

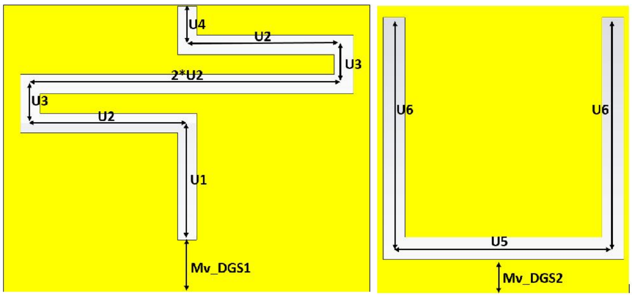
The filter structure was designed on the ground plane at the back of the transmission line by using the DGS method. Fig. 3(a) shows the initial reflection coefficient performance at the desired 2.45GHz resonance frequency, and its second and third harmonics at 4.9 GHz and 7.35 GHz respectively. Therefore, two core designs implement DGSs with different U-shaped slots at the ground plane to eliminate the higher harmonics, as shown in Fig. 3(b). The slot widths are 0.5 mm.



(b)

Fig. 3. Compact Filter analysis (a) Initial return loss of compact antenna (b) Back view of bottom layer FR-4;Filter arrangement with various U-shaped form.

In order to eliminate second harmonic at approximately 4.9 GHz, a unique mirror double U-shaped structure was introduced, as shown in Fig. 4(a). The slot is a combination of mirror-image horizontals, with short straight verticals on the top and bottom structure. The total length of this slot is parameterized as U1+4(U2)+2(U3)+U4. The parameter Mv_DGS1 is defined as distance of the slot from the bottom edges of the FR-4 substrate. All the length parameters were investigated and optimized to ensure the blocking of the second harmonic. Fig. 5 shows the parametric studies on the length U2. It shows that U2 has a significant effect on the reflection coefficient performance between 4.5GHz and 6GHz, when it was varied from 3.5mm to 4.2mm. Increasing the U2 value resulted in an increase in the S11 value at the second harmonic, approximately from –10dB to – 5dB.



(a) (b)

Fig. 4. Details slot structure with it parameters for higher harmonic rejection, (a) DGS1, (b) DGS2.

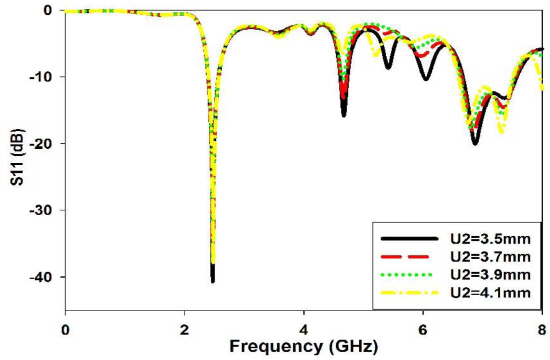
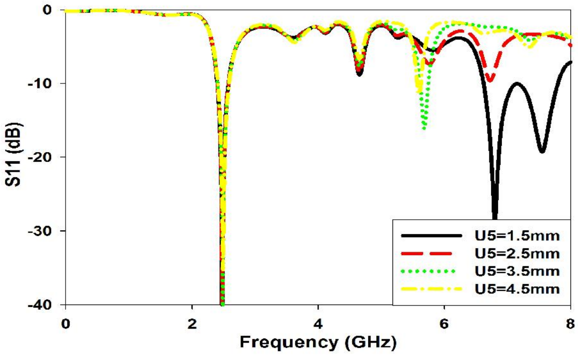
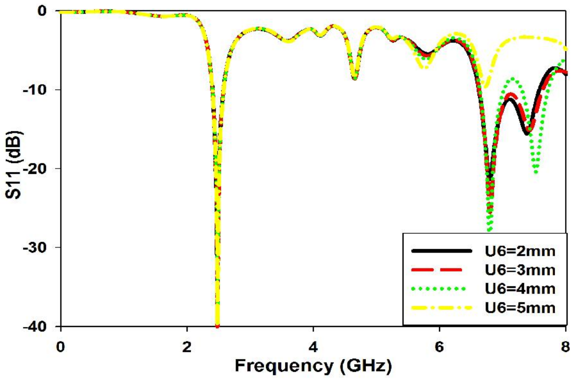


Fig. 5. Reflection coefficient performances with different values of *U2.*

The filter structure performance was further improved to block third harmonic by adding a U-slot at a distance Mv_DGS2 above the first proposed DGS, as shown in Fig. 4(b). Parameters U5 and U6 were analyzed and optimized until third harmonic bandwidth from 6.5GHz until 8GHz was suppressed. Fig. 6 (a) and (b) show the parametric studies with different values of U5 and U6 respectively.



(a)



(b)

Fig. 6. Reflection coefficient performances for (a) *U5*, and (b) *U6.*

All the length parameters were tuned to their best values until the filtenna could resonate at 2.45GHz and reject the second and third harmonics with acceptable S11 values. The optimum value of the proposed structure in milimeter (mm) are Ws1 = 60,Wf = 3, Lf=18, Ls1=60, Ls2=55, Rp=R1=12.5, R2=8.5, Mv_DGS1=2,Mv_DGS2=1,U1=2, U2=4.2, U3=1, U4=1,U5=3 and U6=5.

III. RESULTS AND DISCUSSION

Fig. 7 illustrates the fabricated of proposed filtenna structure on an FR-4 board substrate. The overall filtenna dimension was 60 mm × 60 mm × 3.305 mm. Fig. 8 compares the reflection coefficient performance of the fabricated filtenna with the simulation performance. It can be observed that there is slightly shifted between measurement and simulation.

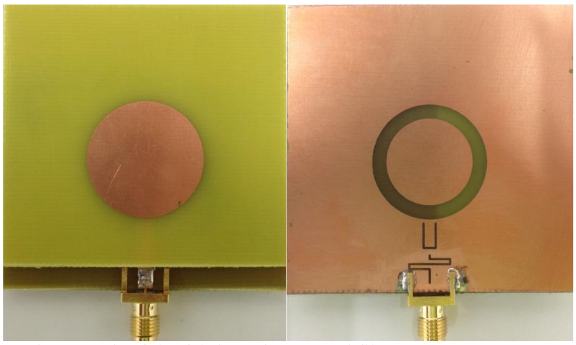


Fig. 7. Photograph of the fabricated proposed filtenna.

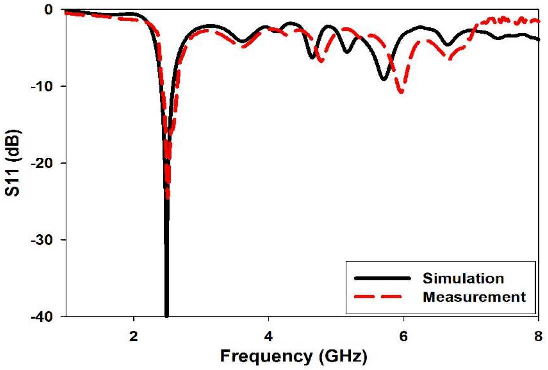
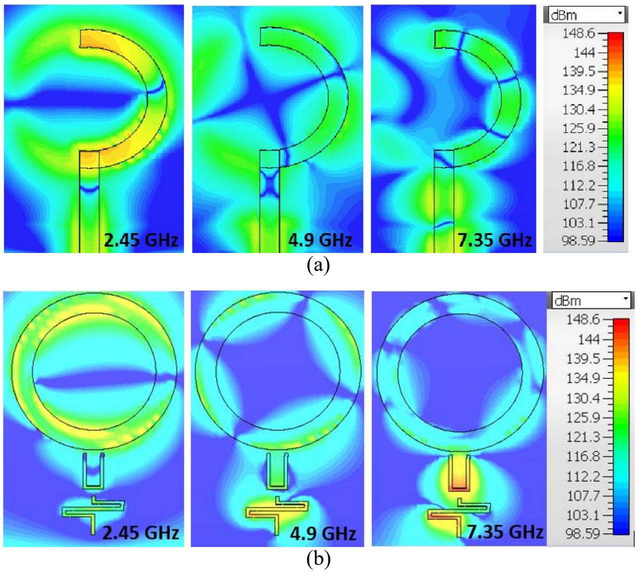


Fig. 8. Reflection coefficient, simulation vs. measuremet.

The results show that the proposed filtenna resonates at 2.48 GHz, with minimum -24.35dB reflection coefficient values, and minimum -39.5dB reflection coefficients at 2.50 GHz for measurement and simulation respectively. The −10dB bandwidth of 240 MHz (2.38-2.62 GHz) for measurement and 200MHz (2.41-2.61 GHz) are observed. The measured reflection coefficients at the blocked second and third harmonics are -4.1 dB and -1.8 dB at 4.9 GHz and 7.35 GHz respectively, while these value are -2.5 dB and -3.5 dB for the simulated case. Fig. 9 shows the simulated electric current distribution in the proposed filtenna structure.



(a)

(b)

Fig. 9. Electric current distribution in proposed filtenna, (a) front view, (b) back view.

This demonstrates that, at the fundamental resonance at 2.45 GHz, current passes to the patch element through the integrated straight line with inverted C-shaped transmission line. At the second harmonic, the current is concentrated on the first U-shaped DGS. At the third harmonic, the current concentration is at both the first and second DGS structures. Consequently, the second and third harmonics are not radiated, since they are blocked by DGS configuration. Fig.10 shows the simulated farfield directivity radiation pattern in a 3-dimensional and polar plot respectively. The antenna patterns are concentrated towards the +Z-direction with an acceptable 5.26 dBi directivity. The simulated xz-plane and yz-plane results of the proposed antenna show acceptable coverage.

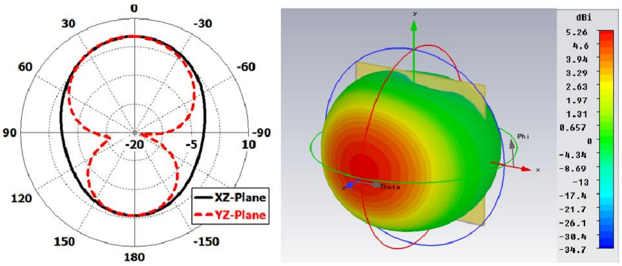


Fig. 10. Far-field directivity radiation pattern in polar plot and 3-dimensional.

IV. CONCLUSION

This paper has presented a numerical design of a compact high harmonic-rejection proximity coupled-fed filtenna with U-shaped DGSs. The designed filtenna is sufficient for operation within the 2.45GHz ISM band. U-shaped DGS structures behind the transmission line act as filters to block higher harmonics, with reflection coefficients of -4.1 dB and -1.8 dB achieved at the second and third harmonics respectively. A circular ring parallel to the patch element was introduced on the ground plane, which effectively reduced patch area by up to 45% as compared to a conventional proximity coupled antenna.

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