Harmonic Suppressed Compact Stepped Impedance Uniplanar Dipole Antenna for WLAN Applications

Manoj Mani*, Remsha Moolat, Kesavath Vasudevan, and Pezholil Mohanan

Abstract—A compact stepped-impedance dipole antenna with harmonic suppression is presented. The antenna occupies an overall size of $40 \times 12 \times 1.6\,\text{mm}^3$ when being printed on a substrate with a relative dielectric constant of 4.4 and loss tangent 0.02. The simulation and experiments are well matched and offer a $2:1\ VSWR$ ($S11 < -10\,\text{dB}$) bandwidth of $590\,\text{MHz}$ at $2.45\,\text{GHz}$. In comparison with a conventional strip dipole, the stepped impedance based dipole antenna shows complete suppression of the first and second harmonics making it suitable as an efficient EMI emission free antenna for widely used Bluetooth and WLAN applications. It can also be employed for wireless power transfer applications with more efficiency.

1. INTRODUCTION

The electromagnetic interference problem caused by higher order harmonics is a bottleneck issue in the design of modern wireless communication systems. For efficient system performance, this undesired higher harmonics emission should be suppressed. In the active integrated antenna's (AIA's) the higher order harmonics are suppressed by adding filters, which in turn results in low transmitter efficiency and high receiver noise figure [1]. Hence, it is appropriate to design a harmonic suppressed antenna devoid of these additional elements.

Traditional harmonic suppressed antennas employ various techniques such as Photonic Band Gap (PBG), Defected Ground Structure (DGS) [2, 3], and stubs/slots in the ground plane [4] for efficient harmonic suppression. The metamaterial-inspired designs are also used to suppress higher harmonics [5]. All these designs have complicated structures, and they are not well suited for uniplanar electronic gadgets. A uniplanar structure, with two slots, etched on the center conductor of the coplanar waveguide feed (CPW) is presented by Ghaffarian and Moradi [6]. PBG structures integrated with CPW fed loop slot antenna are employed efficiently to achieve harmonic suppressed uniplanar antenna [7]. Stacked Patch Antenna with Harmonic Suppression is used for wireless power transfer [8]. The compactness and harmonic suppression characteristics of the SIR antennas were explained in [9, 10]. However, use of a combination of PBG and DGS ground planes makes antenna more bulky and complicated.

In this letter, a novel compact uniplanar Stepped Impedance (SI) based dipole antenna with harmonic suppression is presented. The proposed antenna is simple in design and has efficient radiation characteristics. The significance of the proposed design is the flexibility in tuning its resonant frequency by adopting the standard SIR theory [11, 12].

2. ANTENNA GEOMETRY AND SIMULATION RESULTS

The geometry of the proposed stepped impedance dipole antenna is shown in Fig. 1. The prototype of the antenna was fabricated using the conventional photolithographic process on a substrate of $\epsilon_r = 4.4$, $\tan\delta = 0.02$ and height $h = 1.6\,\mathrm{mm}$, with copper trace thickness (t) of $17\,\mu\mathrm{m}$. The proposed dipole has an overall dimension $40 \times 12 \times 1.6\,\mathrm{mm}^3$, with each arm consisting of two different impedance having widths W_p and W_t to provide an impedance ratio of 0.06. Similarly, the lengths of the two transmission lines are $L_1 = 10.831\,\mathrm{mm}$ and $L_t(L_2 + L_3 + L_4 + L_5 + L_6) = 13.4\,\mathrm{mm}$. The L_t is folded as in the figure to reduce the size of the antenna.
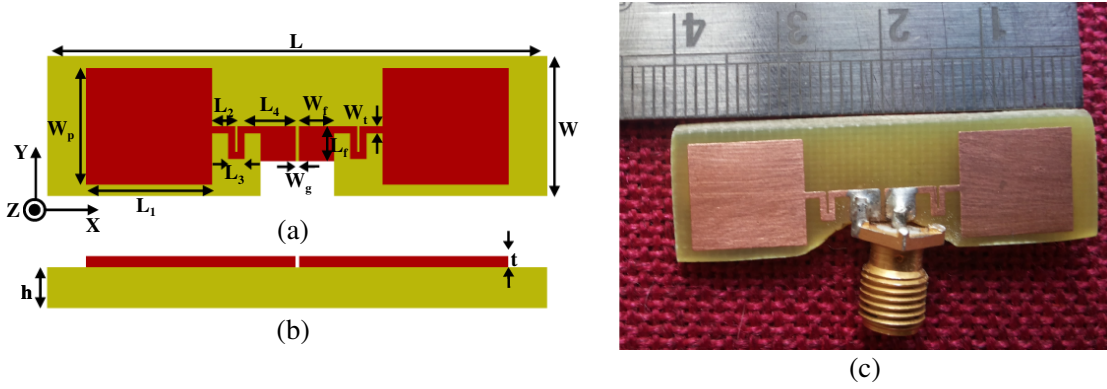

Figure 1. Geometry and dimension of the proposed stepped impedance dipole antenna. (a) Top view. (b) Side View. (c) Photograph of the fabricated prototype. ($L = 40\,\mathrm{mm}$, $W = 12\,\mathrm{mm}$, $L_1 = 10.831\,\mathrm{mm}$, $L_2 = 2\,\mathrm{mm}$, $L_3 = 2.8\,\mathrm{mm}$, $L_4 = 1.4\,\mathrm{mm}$, $L_5 = 2.8\,\mathrm{mm}$, $L_6 = 4.4\,\mathrm{mm}$, $L_f = 3\,\mathrm{mm}$, $W_f = 3\,\mathrm{mm}$, $W_p = 10\,\mathrm{mm}$, $W_g = 0.3\,\mathrm{mm}$ and $W_t = 0.6\,\mathrm{mm}$).

3. RESULTS AND DISCUSSION

The experiments are conducted using Agilent PNA E8362B analyzer and real-time compact bench-top antenna measurement equipment RFxpert (RFX) with an operating frequency range 300 MHz to 6 GHz. Fig. 2 shows the comparison of reflection coefficients of the proposed SI dipole antenna with a conventional standard dipole antenna. The measured $-10\,\mathrm{dB}$ impedance bandwidth of the SI dipole antenna is 23.74 % (2.19–2.78 GHz) as shown in Fig. 2. It is clear that the standard dipole, operating at 2.45 GHz, generates the first harmonic at 4.9 GHz and the second harmonic at 9.8 GHz. In comparison with the standard dipole antenna, it is observed that the SI based dipole antenna suppresses the two
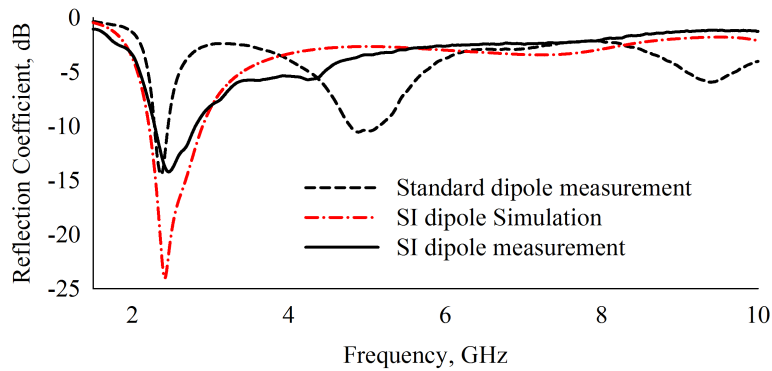

Figure 2. Comparison of reflection coefficients of conventional standard dipole and SI dipole antenna, shown in Fig. 1.

higher harmonics effectively by optimizing the values of W_p and L_1. All simulations are carried out by using commercial 3D electromagnetic simulator CST Microwave studio with time domain solver. The experimental results are in good agreement with the simulation ones. The fundamental resonance of the harmonic suppressed dipole antenna spans over the 2.4 GHz ISM band, which can be easily tuned by adequately choosing the values of impedance ratio (K) and length ratio (α) [13, 14], which is not possible with the standard dipole antenna. In Stepped Impedance Resonators (SIR), fundamental frequency and higher harmonics are determined by the values of K and α. An SIR the impedance ratio is given by $K = Z2/Z1$, where $Z1$ and $Z2$ are the impedance of conducting lines of widths W_t and W_p, respectively. The length ratio is given by $\alpha = \theta_2/(\theta_1 + \theta_2)$, where θ_1 and θ_2 are the lengths of conducting lines of lengths L_1 and L_t, respectively. The curves for length ratio (α) and frequency ratio fs_1/fs_0 (ratio of first harmonic frequency to fundamental frequency) for different K values are plotted in Fig. 3. The relation between length ratio α and fs_1/fs_0 for different impedance ratios is elaborately explained by Nijas et al. [15]. By properly selecting K and α, the ratio of the resonance frequency of fundamental mode to first harmonic can be easily varied, which is demonstrated in Fig. 3. For $W_p = 10$ mm and $W_t = 0.2$ mm, the impedances are 20 Ω and 317 Ω, respectively. As per Fig. 3 maximum separation of fundamental and first harmonic is observed for $K = 0.06$. For compact dipole antenna operating at 2.45 GHz, the impedances are selected as 20 Ω and 317 Ω, respectively, with $\alpha = 0.34$. The width of the 317 Ω line is 0.2 mm on an FR4 substrate. Due to fabrication difficulty, this higher impedance is selected for the present antenna to achieve $K = 0.06$. From Fig. 3, it can be observed that the fundamental and first harmonic frequencies of the stepped impedance dipole with $K = 0.06$ and $\alpha = 0.34$ are 2.45 GHz and 11.94 GHz, respectively. The corresponding measured resonant frequencies of the SI dipole antenna at 2.45 GHz and 11.947 GHz are well matched with the predicted values as per SIR theory.
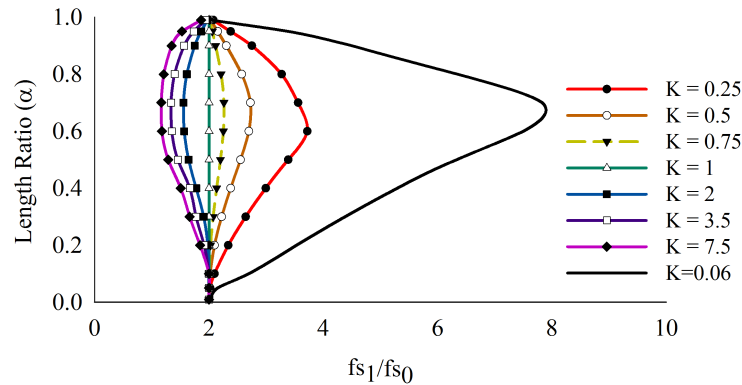

Figure 3. Relation between length ratio α and fs_1/fs_0 for different impedance ratio K.

Figure 4 shows the measured reflection and transmission coefficients of the proposed SI dipole antenna. It is seen from Fig. 4 that the SI dipole antenna efficiently suppresses the first and second harmonics which leads to a complete elimination of noise interferences. The on axis power received by a probe antenna kept at far field distance from the dipole antenna at fundamental. The first and second harmonic frequencies are found to be -15.8 dB, -24.7 dB and -32.6 dB, respectively. It is observed that the maximum radiated power (-15.8 dB) from the dipole antenna corresponds to the fundamental frequency of the SI dipole. At the higher order harmonics the power radiated along the bore-sight direction is negligible (-24.7 dB and -32.6 dB).

The antenna performance is mainly determined by parameters W_p and W_t. To explore the performance of the proposed dipole antenna clearly, extensive parametric study of W_p and W_t has been performed. Fig. 5(a) illustrates the effect of W_p on reflection coefficient from the antenna for a fixed $L_1 = 10.831$ mm and $W_t = 0.6$ mm. It is evident from Fig. 5(a) that the first and second harmonics are completely suppressed when $W_p = 10$ mm. By varying the value of W_t, it is noticed that the fundamental resonance is shifted to the lower frequency with excellent suppression of the first and second harmonics as illustrated in Fig. 5(b). An increase in the width W_t improves the impedance matching in the

operating band. However, full suppression of harmonics with good matching at fundamental frequency is achieved for $W_t = 0.2$ mm.

All the far-field measurements are carried out inside an anechoic chamber, and the results are verified by using RFxpert. Simulated and measured E-plane and H-plane co-polar radiation patterns
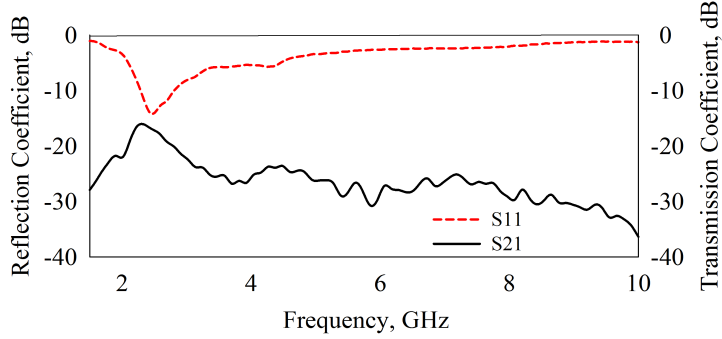

Figure 4. The reflection characteristics ($S11$) and transmission characteristics ($S21$) of the SI dipole antenna.
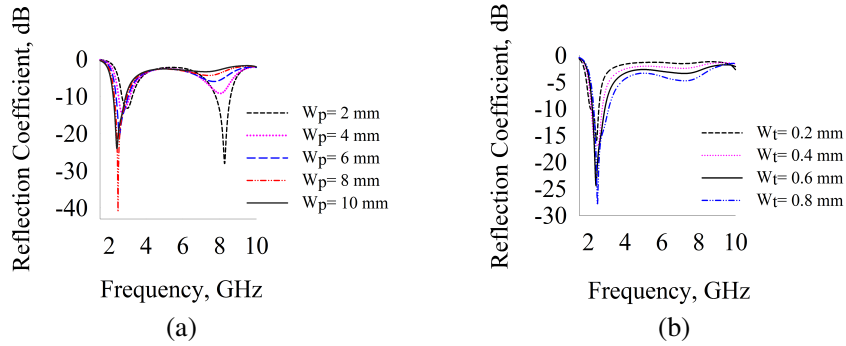

Figure 5. Parametric study of proposed SI dipole antenna. (a) Effect of W_p on antenna perfomance. (b) Variation of W_t for fixed $L_1 = 10.831$ mm and $W_p = 10$ mm.
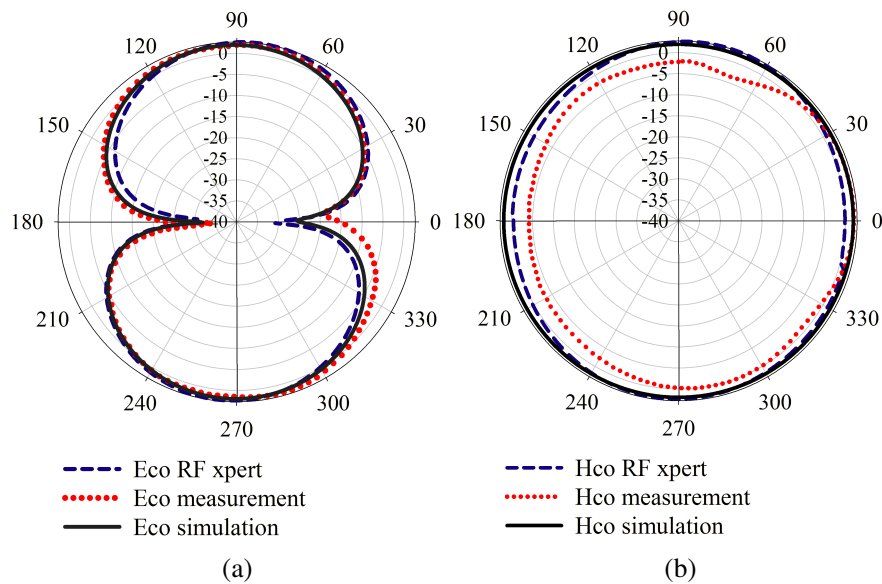

Figure 6. Measured far-field radiation patterns of the SI dipole antenna at resonance frequency 2.4 GHz. (a) E-plane pattern. (b) H-plane pattern.
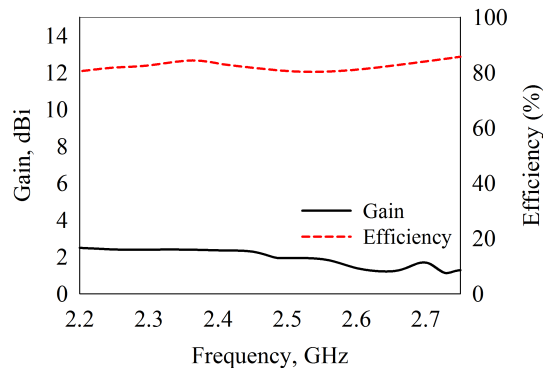
Figure 7. Measured gain and efficiency of the SI dipole antenna.

of the SI dipole antenna at resonance frequency 2.45 GHz are shown in Figs. 6(a) and 6(b), respectively. The measured gain and efficiency of the antenna are plotted in Fig. 7. The gain and radiation efficiency of the proposed antenna at 2.45 GHz are 2.28 dBi and 80.79% respectively as evident from Fig. 7.

4. CONCLUSION

A novel planar stepped impedance based dipole antenna with harmonic mode suppression is proposed. By eliminating the spurious radiation produced at the higher order frequencies, the proposed antenna is well suited for Bluetooth and WLAN wireless applications.

ACKNOWLEDGMENT

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