

A Novel High Gain Low Profile Miniaturized Vertically Polarized Antenna

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Introduction

Research in development of miniaturized antennas has gained significant prominence over the past decade with the growth of wireless technology. Literally myriads of designs using novel topologies and materials have emerged in recent years. One area of practical importance for small robotic platforms and unattended ground sensors is low-profile miniaturized antennas that can generate vertical polarization. Vertical polarization is essential for transceiver nodes that operate near ground since signal path loss for vertically polarized wave is much lower than any other polarization. In [1]–[4], a low-profile, omnidirectional antenna is reported, in which the authors presented a capacitively loaded monopole antenna with a modified top load. The height of these antennas is of the order of $\lambda/10$. However, the lateral dimension of the antennas is comparable to the operating wavelength. Recently, an electrically small antenna with height less than $\lambda/40$ and lateral dimension less than $\lambda/10$ was proposed. This antenna is based on superposition of multiple quarter-wave short-circuited segments that are meandered in a spiral-like configuration [5]. Despite its very interesting principle of operation, it suffers from low gain due to ohmic losses in the metallic traces.

In this paper, we present a new low-profile miniaturized vertically polarized antenna with similar dimensions as in [5] but with considerably higher gain. The antenna structure is appropriate to achieve impedance match to almost any desired input impedance between 10-100 Ohms. In what follows the topology of the antenna is presented and an equivalent circuit model for it is developed for ease of design. Its performance of the proposed antenna is compared to that of ordinary inverted F antennas and Multi-element Monopole Antenna (MMA) [5]. The proposed antenna is fabricated and measured and the measurement results show good agreement with the simulation results.

Antenna Design and Equivalent Circuit Model

The structure of the proposed antenna is shown in Fig. 1. The antenna consists of two copper layers, a shorting pin, a feeding pin and ground plane. The top copper layer is connected to the ground plane through a shorting pin. This shorting pin is isolated from the bottom copper line which is connected with a feeding pin as shown in Fig. 1(b). The radiating element in this structure is the shorting pin which generates vertically polarized radiation. The dimensions of the antenna are as follows: $L_1=L_2=15\text{mm}=\lambda/8$, $L_3= 12\text{mm}$, $L_4=13\text{mm}$, $h_1=1.57\text{mm}$ and $h_2=3.14\text{mm}=\lambda/40$ where λ is free-space wavelength at the resonant frequency. The used substrate has a dielectric constant of 2.2 and dielectric loss tangent of

0.0009. Fig. 2(a) depicts the equivalent circuit model that describes how this antenna works. The shorting and the feeding pins are magnetically coupled which are represented by the two inductors with mutual coupling. Fig. 2(b) shows an excellent agreement between EM full wave simulation and circuit simulation based on equivalent circuit model. The resistance in the equivalent circuit represents the sum of radiation resistance, ohmic loss, dielectric loss and surface wave loss. The top metallic surface is presented by a shunt capacitor in the secondary circuit of the transformer. The uniform current distribution generated by wide copper sheet on the top layer leads to significant reduction of the ohmic loss. Also the turn ratio of the transformer reduces the current in the secondary circuit that is also responsible for the lowering ohmic losses. In other words, the ratio of the radiation resistance to the ohmic loss resistance is significantly improved in this structure, leading to higher quality factor (Q). Impedance matching can be achieved by adjusting the parameters of the transformer and the value of capacitance and inductance. The parameters of transformer correspond to the distance between the shorting pin and feeding pin. The values of the capacitance and inductance are related to the width, length and height of copper sheets in the top and bottom layer. It is interesting to note that using a wide top conductor and the interaction between the shorting and the feeding pins enable excellent impedance matching of an electrically small structure without any bending techniques.

Antenna Simulation and Measurement

The characteristics of the proposed antenna is compared to those of a conventional inverted F antenna with the same vertical profile ($=h2$) based on the simulation results. As shown in Fig. 3(a), the fractional -10 dB bandwidth (FBW) of the proposed antenna is 0.42% at the resonant frequency of 2.347 GHz while the FBW of inverted F antenna is calculated as 0.79% at 2.398 GHz. Thus, the Q -factor of the proposed antenna is higher than that of the ordinary inverted F antenna. Fig. 3(a) shows the simulated and measured return loss. The measurement result shows very good impedance matching. Also the measured antenna gain near the resonant frequency is shown in Fig. 3(b). The measured gain is around -0.5 dBi, which is 6dB higher than an inverted F antenna and 3dB higher than an MMA with the same physical dimensions, as shown in Table I. Also the use of wide conductor in the proposed antenna leads to excellent suppression of horizontally polarized radiation. The difference between the co-pol and the cross-pol in the H-plane ($\theta=90^\circ$) is more than 25 dB as shown in Table I, compared to inverted-F type antennas which suffer from higher horizontal radiation due to their long lateral arm. As shown in Table I and Fig. 4(b), cross-(=horizontal) polarized radiation of a low-profile inverted-F antenna is 5dB higher than co-(=vertical) polarized radiation. Although MMA shows much better suppression of horizontally polarized radiation by the novel geometry which cancels out the horizontal current distribution, it still suffers from some horizontally polarized radiation due to edge current [5].

Conclusion

A new type of low-profile miniaturized vertically polarized antenna for gain enhancement is proposed. The operation of the proposed antenna was analyzed based on an equivalent circuit model. The unique characteristics of this antenna are studied and compared to previous low-profile antennas. The gain of the proposed antenna is 6dB and 3dB higher than that of inverted-F antennas and MMAs with the same physical dimensions. Moreover, the ratio of the co-pol to the cross-pol level on H-plane is more than 25 dB. If the maximum cross-pol gain in the E-plane ($\Phi=90^\circ$) could be improved, this antenna can be used in MIMO applications, which require two uncorrelated different polarizations.

References:

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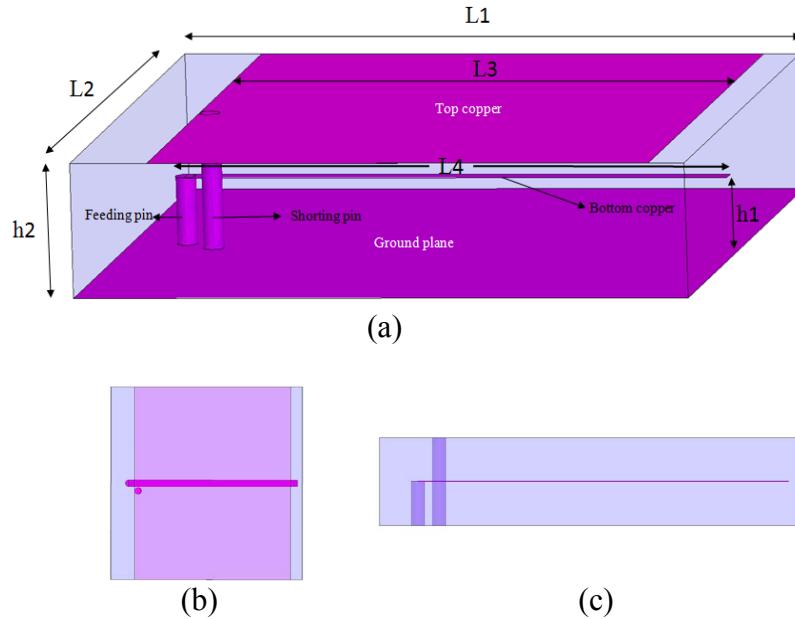


Fig. 1. (a) The proposed antenna an its dimensions (b) Top-view (c) Side-view

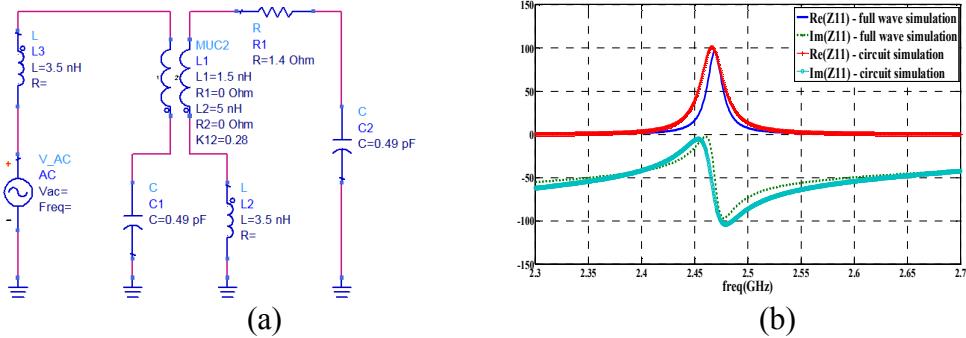


Fig. 2. (a) The equivalent circuit model and (b) Z_{11} by full wave and circuit simulation

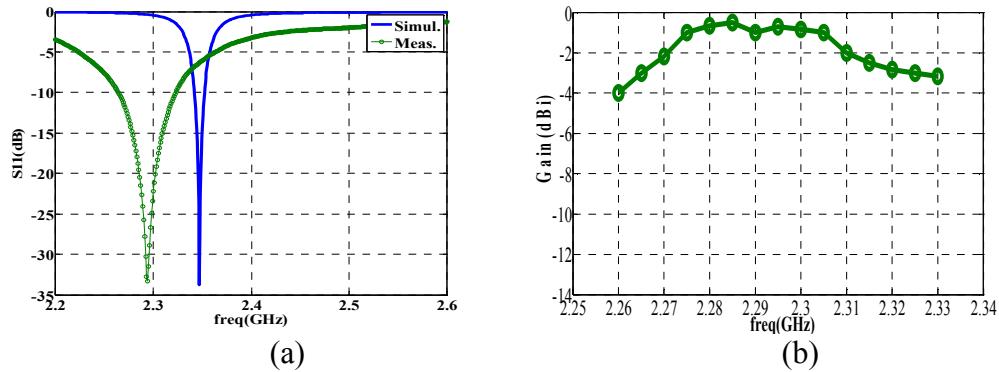


Fig. 3. (a) Simulated and measured S_{11} (b) Measured Gain near the resonant frequency

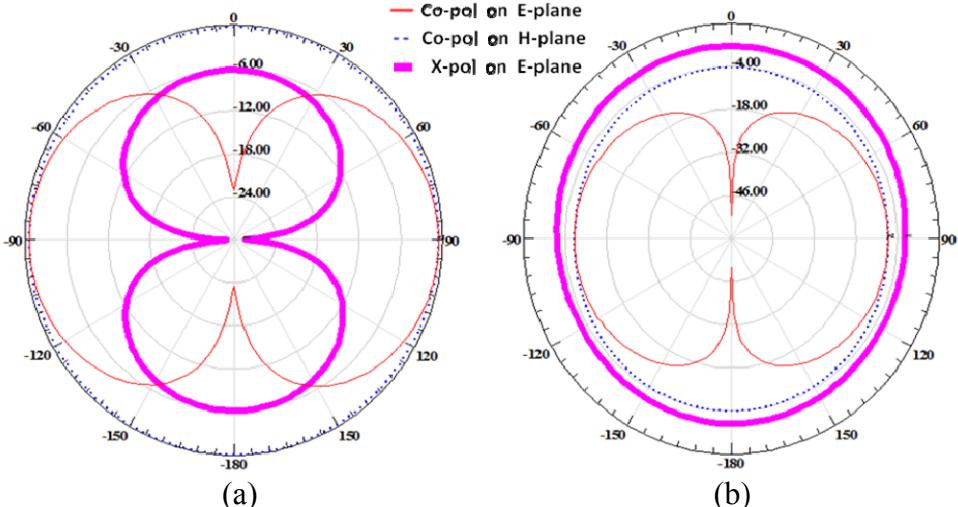


Fig. 4. Radiation patterns of (a) proposed antenna and (b) inverted-F antenna

Antenna type	Lateral dimension (mm X mm)	Height (mm)	Gain (co-pol= vertical pol) on H-plane	Gain (cross-pol) on H-plane	Co-pol to cross-pol (dB)
Inverted F Antenna	18 X 36	3.14	-7.1	-1.3	-5.8
MMA	15 X 15	3.14	-3.6	-5.2	1.6
Proposed Antenna	15 X 15	3.14	-0.6	-28.4	27.8

TABLE I. Calculated results of several type low-profile antennas