ISM 433-MHz Miniaturized Antenna Using the Shielding Box of Mobile Terminals

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***Abstract*—A miniaturized monopole antenna for ISM 433-MHz frequency band is designed, fabricated, and measured. The whole structure proposed in this letter consists of a metal shielding box for transceiver circuit, a rectangular ground for battery, and a meander-line monopole. The size of the structure is 51×82 mm^2, and the area left of the antenna itself is just about 49×13 mm^2. To make the antenna work in such a small area, and maintain good performance, the metal shielding box of the transceiver circuit in this work is connected to the meander-line monopole. Actually, the shielding box does not serve as a part of the ground, but a part of the antenna itself, which plays an important role in matching and increasing the antenna's electrical length. Meanwhile, no additional area is needed compared to the conventional design. The measured -10-dB bandwidth is 5 MHz. The comparison between the traditional design and the proposed design as well as the critical parameter study is presented in this letter.**

***Index Terms*—ISM 433-MHz wireless system, handset antenna, impedance matching, monopole antenna.**

I. Introduction

It IS well-known that the ISM 433.050–434.790-MHz frequency bands [1] are used for low-data-rate applications, such as wireless sensor network (WSN). Due to the rapid development of the wireless communication, the size of the wireless system operating at this frequency band should be small and compact. The free-space wavelength corresponding to 433 MHz is 0.692 m, and the size of the usual antennas would be too huge to integrate in a system as large as a business card. Thus, the volume is the most concerning problem for an antenna design. Another concern for the antenna is performance. As the volume of the antenna decreases, the radiation resistance gets smaller and quality factor gets higher, resulting in low total efficiency and narrow bandwidth. Hence, how to reduce the size of the antenna and maintain the performance is the biggest challenge in the design.

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One way for the miniaturization of antennas is the utilization of lumped elements [2]–[4]. In [2], a magnetic monopole loaded with a capacitor is presented for ISM 433-MHz band applications. It is designed on a printed circuit board (PCB) with size of 103×55 mm^2, and at least 3-MHz bandwidth is achieved. To increase the electrical length of the current path efficiently in a given area, special geometry, such as meander lines, is used [5]–[7]. In [5], a two-rectangular-printed-spiral antenna with a U-strip is proposed, with a dimension of $50 \times 50 \times 1.6$ mm^3, and 5.455% bandwidth and -5 dBi gain are achieved. In [6], Ryu *et al.* presented a folded monopole antenna using a C-shaped meander for active 433.92-MHz RFID tag, achieving 3.52 MHz (0.81%) bandwidth, with the height and diameter of the antenna 20 and 34 mm, respectively. In [7], a meander microstrip planar antenna is presented, achieving at least 5 MHz bandwidth and -6 dBi gain, with the size of the antenna element 20×37 mm ^{2} and the length of ground plane 30 mm. A more straightforward way for miniaturization is to increase the material loading by increasing the relative permittivity or the relative permeability of the substrate [8]–[10]. In [8], a special magneto-dielectric material is used in the antenna design and the highest dimension is lower than $\lambda/42$ (λ is corresponding to 470 MHz).

In this letter, a novel antenna design solution for a wireless device operating at ISM 433-MHz frequency band is reported. The proposed structure consists of a meander-line monopole, a metal shielding box for the transceiver circuit, and a ground for both the antenna and the battery. The metal shielding box is connected to the meander-line monopole. The size of the system is 82×51 mm ^{2}, about $0.11\lambda \times 0.07\lambda$ (λ is corresponding to 433 MHz), and the size of the antenna itself is 49×13 mm^2, about $0.7\lambda \times .016\lambda$. The novel solution makes the electrically small antenna work without the help of lumped elements. The measured -10-dB bandwidth is 5 MHz. Details of the proposed antenna and both the simulated and measured results are presented and discussed.

II. Antenna Design

Basically, a wireless device operating at ISM 433-MHz frequency band consists of a transceiver circuit, a battery, and an antenna. Considering the electromagnetic compatibility, a metal box shielding the transceiver circuit is needed. How to integrate them into such a small area as large as a business card and realize acceptable antenna performance becomes a big problem. The traditional antenna design solution is shown in Fig. 1. The antenna works like a meander-line monopole. The area occupied by the battery is reused as the monopole's ground. The metal shielding box is usually connected to the battery ground. Thus,

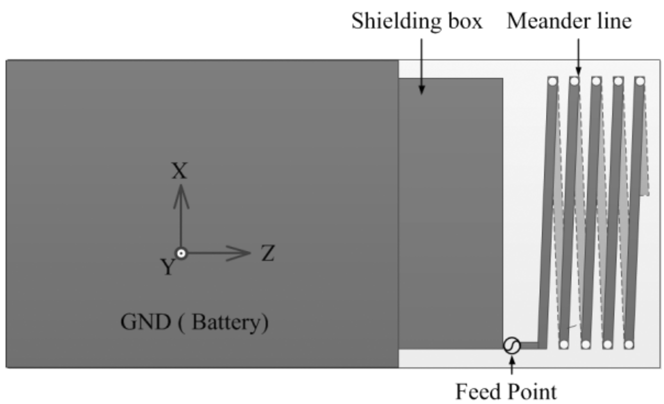


Fig. 1. Geometry of the traditional system design for ISM 433–MHz frequency band.

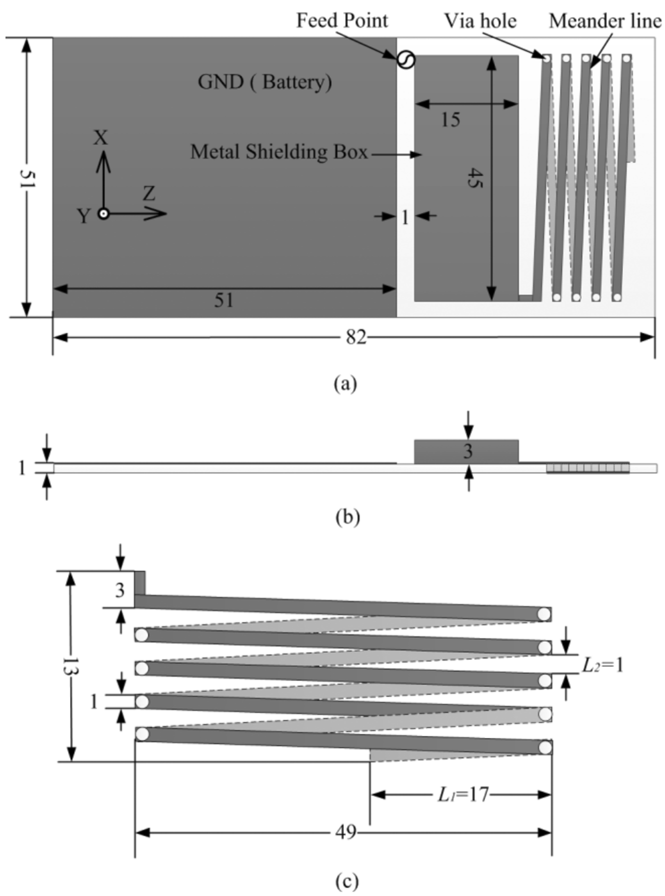


Fig. 2. Geometry of the proposed antenna (unit: millimeters). (a) Top view. (b) Side view. (c) Detail parameters of the meander line.

the area left of the antenna is quite small, and the impedance matching is poor.

The configuration of the proposed antenna is shown in Fig. 2. The antenna is fabricated on the low-loss Teflon ($\varepsilon_{\mathrm{r}} = 2.65$) substrate board with a dimension of $82 \times 51 \times 1$ mm^3. The ground printed on the front side of the Teflon substrate has a length of 51 mm. In this letter, only the antenna design is concerned, and the transceiver circuit is not contained. The volume of the shielding box is $45 \times 15 \times 3$ mm^3. The distance between the ground and the shielding box is 1 mm. The 1-mm-wide metal meander line is connected to the shielding box and goes around the substrate board through via-holes and finally ends on the backside of the board. The final details of the meander line are shown in Fig. 2(c). The pitch of each turn of the meander line (L_2) is 1 mm, and the length of the last part of the meander line (L_1) is 17 mm. The whole size of the meander line itself is 49×13 mm^2. Both the traditional and proposed antennas are fabricated and shown in Fig. 3.

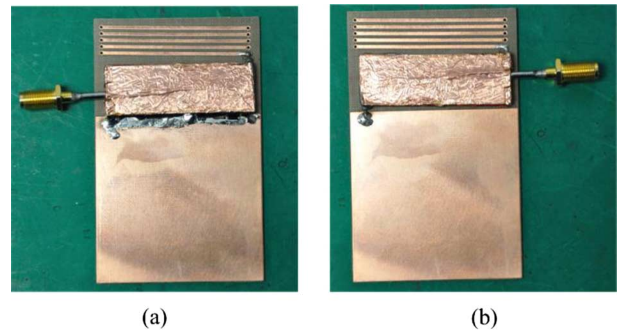


Fig. 3. Fabricated prototypes of (a) the traditional and (b) the proposed antenna.

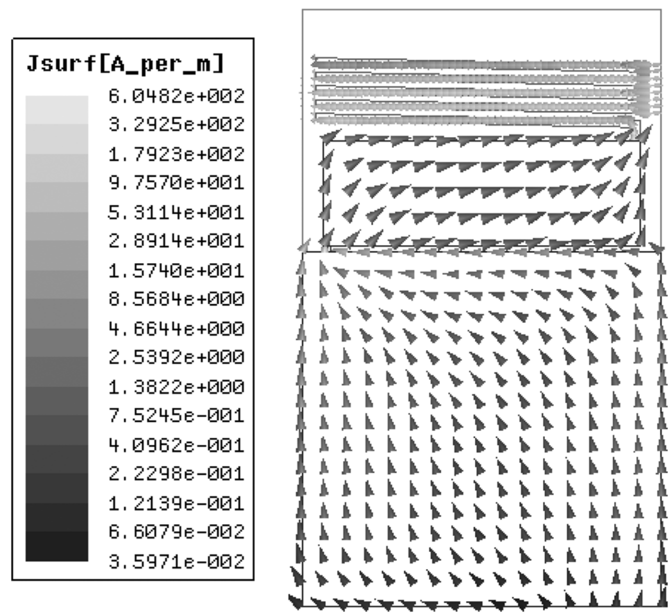


Fig. 4. Simulated surface current distribution of the proposed antenna.

In the traditional design, it is difficult to match the antenna without the help of lumped elements. However, lumped elements used in the matching circuit will cause additional loss and degrade the antenna performance. To make the monopole work without any lumped element, the shielding box is connected to the meander-line monopole instead of the ground. The area occupied by the antenna is increased efficiently, which results in good impedance matching. Actually, the metal shielding box does not serve as a part of the ground anymore, but a part of the monopole antenna. It should be noted that the size of the whole structure remains the same after the change.

The feeding method is also changed as shown in Fig. 3. As the metal shielding box is now connected to the meander-line monopole, the signal line coming out of the shielding box should be connected directly to the battery ground instead of the meander line, which makes the whole structure work as a monopole. The corresponding current distribution is shown in Fig. 4.

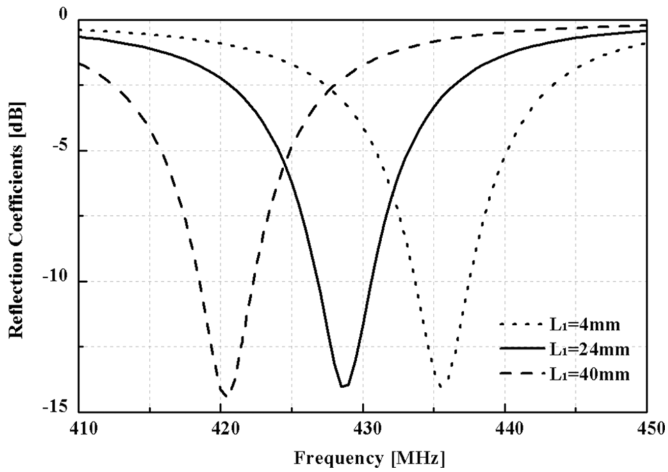


Fig. 5. Simulated reflection coefficients for different values of L_1.

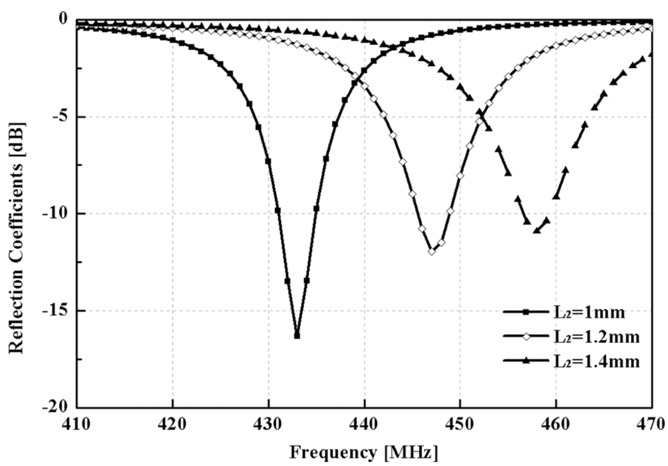


Fig. 6. Simulated reflection coefficients for different values of L_2.

To accommodate all the structures in a small volume, a meander-line monopole is used. The structure of the meander line plays an important role in determining the center frequency and the impedance matching. Fig. 5 shows the impendance behavior with the changing of L_1. As L_1 gets smaller from 40 to 9 mm, the resonant frequency gets higher from 420 to 436 MHz. Hence, the resonant frequency can be controlled easily and precisely by adjusting L_1 in the design. Fig. 6 shows the impendance behavior with the changing of L_2. L_2 gets smaller from 1.4 to 1.0 mm, which means the total length gets a little shorter, but the resonant frequency gets lower. Actually, as L_2 gets smaller, the total length of the meander line changes slightly compared to the wavelength. However, the coupling between the meander lines gets stronger and affects the resonant frequency significantly.

III. Experimental Results

The simulated numerical results using Ansoft's HFSS [12] are presented and compared to the measured ones. In the simulation, the metal loss and the dielectric loss are included. Teflon's dielectric loss tangent is set to be 0.005, and the metal shielding box is made of copper.

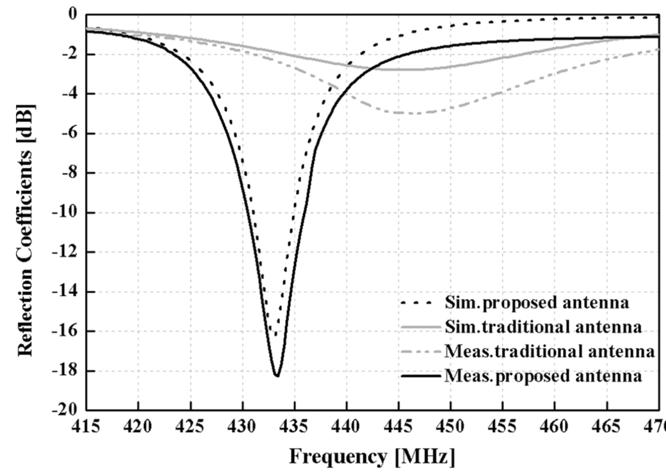
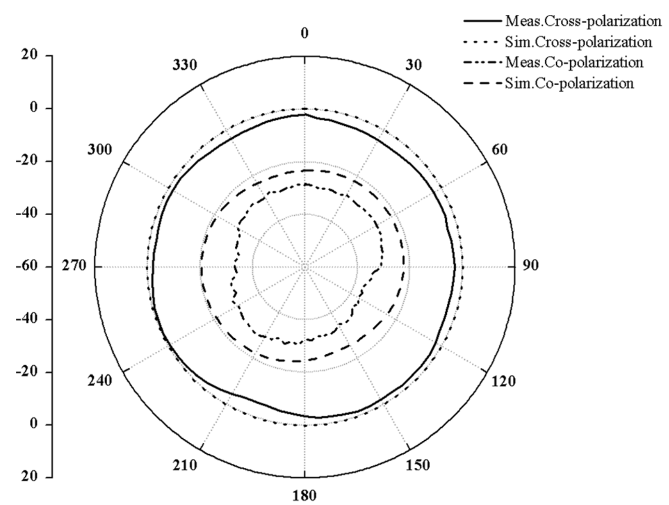
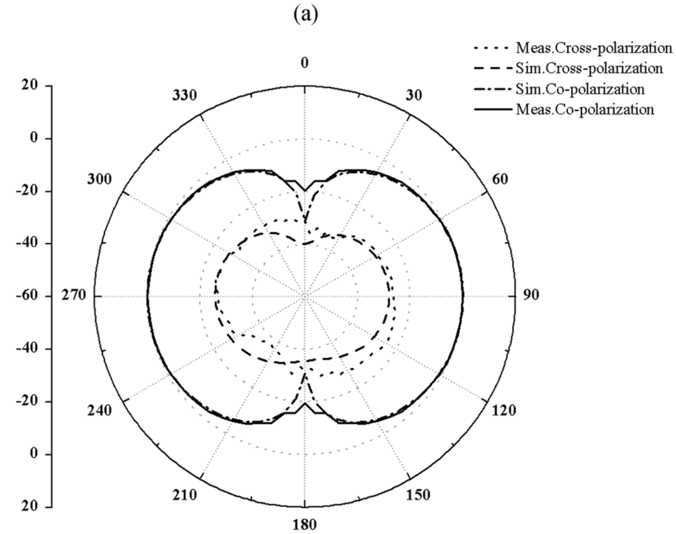


Fig. 7. Measured and simulated reflection coefficients of the proposed and traditional antenna.



(a)



(b)

Fig. 8. Simulated and measured normalized radiation patterns of the fabricated prototype at 433 MHz. (a) H-plane (xz-plane). (b) E-plane (yz-plane).

Fig. 7 shows the simulated and measured return losses of the tradition design and the proposed design. The simulated center frequency of the proposed antenna is 433.1 MHz, and the -10-dB bandwidth is 3.6 MHz, covering ISM 433.050–434.790-MHz frequency band. As is mentioned earlier, in the measurement, to simulate how the system works in practice, a 50-Ω coaxial cable goes through the metal shielding box, with the inner conductor connected to the battery's ground and the outer conductor connected to the metal shielding box. In the traditional design, the shielding box serves as a part of the ground, and the inner conductor is directly connected to the meander line, which is different from the proposed design. To suppress the current flowing along the outside of the cable, ferrite beads are used here [11]. Detailed configuration is shown in Fig. 3. The measured center frequency of the proposed antenna is 433.7 MHz, and the measured -10-dB bandwidth is 5 MHz. The difference between the simulated and measured center frequency is slight and acceptable. The measured bandwidth gets wider from 3.6 to 5 MHz. There may be two reasons. First, there may be more loss induced by copper, dielectric, and cable in the measurement than simulation. Second, there may be a little leaking current flowing along the outside of the cable despite of the use of ferrite beads, both resulting in the change of the impendance matching and bandwidth.

The measured normalized radiation patterns in H-plane (xz) and E-plane (yz) at 433.7 MHz are shown in Fig. 8. Good omnidirectional pattern has been achieved in the xa-plane, and the yz-plane is quite close to bidirectional. The max gain simulated and measured at 433.7 MHz are -3.5 and -4.3 dBi, respectively, which shows acceptable agreement.

IV. Conclusion

A novel and electrically small antenna ($82 \times 51 \times 1$ mm^3 for the system substrate board; 49×13 mm^2 for the proposed antenna itself) is designed for ISM 433-MHz frequency band. For the wireless system operating at such a frequency band, to integrate a transceiver circuit, battery, and antenna in such a small area and maintain the performance of the antenna is difficult for the traditional design. In this letter, a new solution for such requirements is realized by connecting the metal shielding box to the meander-line monopole, which makes the shielding box itself a part of the antenna. No additional room is required for achieving an acceptable antenna performance. The measured -10-dB bandwidth of the proposed antenna is 5 MHz (1.3%), covering the ISM 433.050–434.790-MHz frequency band. The max gain measured at 433.7 MHz is -4.3 dBi. The proposed antenna has the advantages of low profile, acceptable performance, and easy implementation, which is quite suitable for wireless applications at ISM 433-MHz frequency band.

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