Research Article

Cavity-Backed Dipole Antenna for Intelligent Lock Communication

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This paper introduces a $20 \times 40 \text{ mm}^2$ planar folded L-shaped dipole antenna operated under surroundings of an iron cavity for intelligent lock communication. The height of the slot antenna is shortened and the bandwidth for 2.4 GHz band has been widened. This antenna provides a solution for antenna surrounded by metal background. Good performances on return loss, radiation pattern are obtained over 2.4 GHz operating bands. The operation distance in front and back sides for the antenna has been calculated by Friis transmission equation.

1. Introduction

With the recent developments of wireless communication systems, the radiation antennas with unidirectional radiation pattern for cavity-backed applications are in great demand, such as substrate integrated waveguide (SIW) cavity-backed antenna or just metallic-backed surfaces or cavity in [1]. Cavity-backed slot antenna shows good characteristic. Luo et al. [2], proposed a SIW cavity-backed slot antenna for 10 GHz. A lot of applications of cavity-backed slot antennas had been given in [3–5]. However, in practice, the shape of cavity behind the antenna is complex and even not complete. So, how to deal with this situation is really a challenge. On the other hand, the front-to-back ratio needs to be above 20 dB. So how to properly design the antenna and position the antenna is the second problem we need to solve. From Friis transmission equation, how to calculate the relationship between distances the antenna radiates and the input power is the third issue.

In this paper, we proposed a cavity-backed dipole antenna for intelligent lock application. The slot antenna for cavity-backed case cannot be used in our design; this is because the slot is too wide to be excited compared with [3–5]. Other kinds of independent antenna should be taken into account. When a metal is placed too near to the antenna, it will introduce a significant capacitance to its input impedance; thus, it will sharply reduce the bandwidth of the antenna, and

the resonant frequency of it will change [6]. So for balanced antenna, it does not excite the basic (ground) mode; we have to place it to the proper position and orientation and preserve enough distances from the metal (the iron cavity) to the antenna. Calculating the distances the antenna can radiate is practical for real life. By adopting Friis transmission equation, we calculated the front-to-back distance ratio; the antenna would work under the requirement of distance of 3 m and 20 cm in the front and back. The resonant frequency of the antenna is chosen to be 2.4 GHz band and the bandwidth of the antenna needs to be cooperated with CC2500 RF transceiver, so the bandwidth of the frequency needs to cover 2400.0 MHz~2483.5 MHz. As the remote sensor only has to transport password to the intelligent lock, the data volume is small, so the bandwidth and efficiency are not a key characteristic for this antenna. The size of the iron lock is $290 \times 70 \times 25 \text{ mm}^3$ and the thickness of the iron lock is 6 mm, so it has been hollowed with a space of $278 \times 58 \times 13 \text{ mm}^3$. The whole cavity has been considered as a reflector for the dipole antenna, while the cavity-backed slot antenna and SIW cavity-backed antenna have considered the whole cavity as a part of the antenna in [2–5]. For the properly designed target of unidirectional radiation pattern, we do not have to consider the iron cavity as a part of the antenna. However, for the strong coupling effect, a part of the energy has been coupled into the iron cavity, so the bandwidth has been narrowed; the efficiency would be reduced. We have

FIGURE 1: Configuration and dimensions of the proposed printed dipole antenna (unit: mm).

FIGURE 2: Simulated return loss for the proposed printed dipole antenna.

compared the results of the antenna with and without the iron cavity. This is also the drawback of the antenna. The antenna has been folded to two L-shapes to reduce the length of it.

2. Antenna Design and Analysis

For a simple planar dipole antenna working at 2.5 GHz band, the size of the antenna, the return loss, and its radiation pattern of xz and yz planes simulated by HFSS13 have been given in Figures 1, 2, and 3, respectively. From Figure 1, we can see that the size of the dipole antenna has been reduced to $40 \times 20 \text{ mm}^2$; the branch of the dipole has been folded to L-shape to reduce the length of the branch. The antenna is fabricated on a 1 mm thick FR4 substrate of relative permittivity 4.4 and loss tangent 0.02. From Figure 2, one can see that the central resonant frequency of the antenna is 2.5 GHz. The bandwidth is large enough to cover 2.4–2.65 GHz under 10 dB return loss. From Figure 3, one can get that the radiation pattern of the dipole antenna is omnidirectional. According to the geometry theory of diffraction (GTD), the corrugated ups and downs in Figure 3(b) are caused by the interference between the radiation field and the diffraction field [6].

When an iron cavity is placed at the back of the dipole antenna, the strong coupling effect would introduce a significant capacitance (reactance component) to the antenna input

impedance, which can cause the energy to be reflected at the antenna feeding terminals due to impedance mismatching to real impedance. On the other hand, the iron cavity would act as a reflector for the printed dipole antenna; the radiation pattern of the antenna would be unidirectional. The size of the iron cavity, the return loss of the printed dipole antenna, and the radiation pattern at 2.4 GHz have been given in Figures 4, 5, and 6, respectively.

In Figure 4, the size of the iron cavity is $290 \times 70 \times 25 \text{ mm}^3$, the thickness of the cavity is 6 mm, and the inner part of the cavity is hollowed. A $97 \times 58 \times 6 \text{ mm}^3$ window has been opened on the iron cavity. The printed dipole antenna is at the right side of the window. From Figure 5, one can see that the bandwidth of the dipole antenna has been narrowed compared with Figure 2; this is because that the energy has been coupled into the iron cavity, and the iron cavity introduces a capacitance (reactance component) to the antenna input impedance. On the Smith Chart the resonant frequency would be deviated from the central point. Although the distance between the antenna and the iron cavity is beyond the Fraunhofer region, the strong coupling effect cannot be ignored. The bandwidth of the antenna under the surrounding of an iron cavity is 2.4 GHz–2.48 GHz of 10 dB return loss. In Figure 6, the radiation pattern of the antenna becomes unidirectional, and the front-to-back ratio for the gain is nearly 28 dB.

3. Calculation

The Friis transmission equation can be expressed as follows in its simplest form [7]:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2. \quad (1)$$

Given two antennas; P_r is the power available at the input of the receiving antenna, P_t is the output power of the transmitting antenna, where G_t and G_r are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas, respectively, λ is the wavelength, and R is the distance between the antennas. To use the equation as written, the antenna gain may not be in units of decibels, and the wavelength and distance units must be the same. If the gain has units of dB, the equation is slightly modified to

$$P_r = P_t + G_t + G_r + 20 \log_{10} \left(\frac{\lambda}{4\pi R} \right). \quad (2)$$

Gain has units of dB, and power has units of dBm or dBW.

For front side and back side of our dipole antenna, we add f and b to the subscripts in (2). Equation (2) for front and back sides of the antenna becomes

$$P_{rf} = P_{tf} + G_{tf} + G_{rf} + 20 \log_{10} \left(\frac{\lambda}{4\pi R_f} \right), \quad (3)$$

$$P_{rb} = P_{tb} + G_{tb} + G_{rb} + 20 \log_{10} \left(\frac{\lambda}{4\pi R_b} \right), \quad (4)$$

where P_{rf} and P_{rb} are the receiving power in the front and back sides. P_{tf} and P_{tb} are the transmitting power in the front

FIGURE 3: Simulated radiation patterns at 2.4 GHz.

FIGURE 4: Configuration and dimensions of the proposed printed dipole antenna backed by an iron cavity (unit: mm).

and back sides. G_{tf} and G_{tb} are the transmitting antenna's gain in the front and back sides. G_{rf} and G_{rb} are the receiving antenna's gain in the front and back sides. R_f and R_b are the distances between the antennas in the front and back sides. Well, in our design, the antenna in remote sensor has fixed receiving power and gain in front and back sides, so $P_{rf} = P_{rb}$, $G_{rf} = G_{rb}$. The antenna in our design is the transmitting antenna for (2), the transmitting power for the front and back sides is equal, so $P_{tf} = P_{tb}$. However, from Figure 6, one can see that gain of the designed antenna in the front and back

FIGURE 5: Simulated return loss for the proposed cavity-backed printed dipole antenna.

sides has 28 dB differences, so $G_{tf} - G_{tb} = 28$ dB. Subtract (4) from (3), one can get

$$G_{tf} - G_{tb} = 20 \log_{10} \left(\frac{R_f}{R_b} \right). \quad (5)$$

So, $R_f/R_b = 25$. The distances in front side between the antenna of remote sensor and antenna of our design are 25 times that in the back side. That means when one properly adjusts the transmitting power and receiving power of the antennas in the remote sensor and the intelligent lock, the distance for the front side can be tuned to 3 m, and then the distance for the back side is only 12 cm. It would be useful for the intelligent lock communication. The lock could be opened by the remote sensor in 3 m in the front side and could not be opened larger than 12 cm in the back side. This function is much useful and safer for the customers.

FIGURE 6: Simulated radiation patterns at 2.4 GHz.

4. Conclusion

In this paper, we introduced a printed dipole antenna backed by a special-shaped cavity for the intelligent lock communication. The difference between the traditional printed dipole antenna and the metal nearby dipole antenna has been discussed and explained. The distance for the front-to-back ratio has been calculated. This antenna shows good characteristic for wireless communication for the intelligent lock of unidirectional radiation pattern and enough bandwidth.

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