Research Article

Double Loop Inductive Feed Patch Antenna Design for Antimetal UHF RFID Tag

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Planar UHF RFID antimetal tag can be widely used for the metallic products or packages with metal material inside. A double loop inductive feed planar patch antenna is proposed for UHF RFID tag mounted on metallic objects. Compared to conventional microstrip antennas or PIFA antennas used for UHF RFID tags, the double loop inductive feed patch antenna has a planar structure, with no short via or short wall, which could decrease the manufacturing cost of the tags. The double loop inductive feed structure also increases the radiation performance of the planar antenna. Moreover, the double loop inductive feed structure makes the impedance of the patch antenna be tuned easily for conjugate impedance matching.

1. Introduction

Radio frequency identification (RFID) in the ultrahigh frequency (UHF) band is gaining more and more attention recently because of its long read range, fast read rate, and low cost. In many cases, the UHF RFID tags are required attaching to the surface of metal objects, for instance, steel cups and packages with metallic foil inside. However, it is difficult for the UHF RFID tags to work properly on the surface of metal objects, especially when the tags are with dipole label-type antennas. When the tags are placed on the metallic surface, the parameters of the tag antenna, such as the input impedance, the radiation efficiency, and the radiation pattern, are changed [1]. To improve the performance of the tag for metal objects, several microstrip antennas and PIFA (Planar inverted-F antenna) antennas, which use the metallic surface as ground, have been proposed [2, 3]. These kinds of antennas could electromagnetically isolate themselves from the matter behind the ground plane. Also, many different patch antennas and PIFAs have been proposed to achieve bandwidth improvement, size reduction, and longer tag reading ranges [4–9]. Most commercial antimetal UHF RFID tags also adopt these design methods. However, these kinds of antennas normally have short walls or via holes, which cannot be printed with silver or aluminous ink in mass production with low cost as that of label-type antennas. The printing technique is very promising for the RFID tag design and production, which can be printed with conductive ink and can be flexibly customized. For the antimetal tag antenna, which has several millimeters thick, the shorting walls and vias would make it difficult for the printing technique to be used.

To be produced with the printing technology, the antenna and its feeding structure should be completely planar, which means there is no via hole or short wall. Only a few literatures report about planar UHF RFID tag antenna used for the metallic surface. The main choice for the planar tag antenna design is still the dipole-like antenna [10–12], including some double loop dipole antennas [13, 14]. There are also some metal-mountable tags based on dipole antennas integrating EBG structures [15, 16]. The EBG structure is based on circular slots arranged in a square lattice in the ground plane, which can achieve better reading range and platform tolerance. But in these
EBG structure antennas, the nonplanar structures are still required. Apart from that, some metal-mountable tags based on antennas without a ground plane are proposed, but with slot structure and high-permittivity substrate material [17–19]. For the commercial solutions, some companies use the wave absorbing material between the dipole-like antenna and the metal surface, which will increase the cost of the label obviously.

Few planar patch antennas are designed for the metallic environment [20, 21], using a big ground plane or open stub feeding structure. However, most of these planar tag antennas have low radiation efficiency and are difficult for impedance matching. Likewise, similar problems have also been shown in a conformal RFID tag antenna and an antenna with miniaturization for using on perishable goods and human beings [22, 23]. There are some flexible planar tag antennas, such as the flexible wideband UHF RFID tag antennas for curved metal surfaces and the low profile flexible metal mountable UHF RFID tag antennas [24]. Although these designs are simple and without shorting pins for interconnecting, it also has the shortcoming in radiation efficiency and impedance matching [24, 25].

In this paper, a completely planar UHF RFID tag patch antenna with a double loop inductive feed is proposed. There is no via hole or short wall between the radiation patch and the ground, which means the antenna can be fabricated easily in the mass production. The double loop inductive feed structure makes the planar patch antenna has a better radiation performance than the dipole-type antennas for the metallic surface. By changing the length of the double loop and the width of the inductive gap, the impedance matching of the antenna could also be achieved well. The structure and principle of the antenna are introduced first. Then, the simulation and optimization of the antenna are calculated by the EM simulation software HFSS 12. The prototype of the antenna was fabricated, and the performance of the antenna was tested by a commercial reader in an anechoic chamber. The experiment results show that the planar UHF RFID tag patch antenna with a double loop inductive feed has a good radiation performance and flexible impedance matching ability when used on metal.

2. Antennas Design

For a normal UHF RFID tag antenna, the main considerations for the design are the good impedance matching, good radiation efficiency, and good antenna gain. If the tag antenna is used for metallic surface, the ground plane should be considered. And here, another consideration is the planar design, which means no via hole or short wall between the radiation patch and the ground. In our design, a planar patch antenna with a planar ground is used for this antimonial tag antenna design, and the double loop inductive feed structure is used for impedance tuning and optimization.

The most important consideration for the UHF RFID tag antenna design is the impedance matching between the chip and antenna. For a UHF RFID tag antenna, the power transmission coefficient between the chip and the antenna is calculated as follows:

\[
\tau = \frac{4R_c R_a}{|Z_c + Z_a|^2},
\]

where \(Z_c = R_c + jX_c\) is the impedance of the tag chip, and \(Z_a = R_a + jX_a\) is the impedance of the tag antenna. When the impedances of the antenna and the chip are conjugate matching, the transmission coefficient \(\tau\) could get the maximum value and most energy will be transmitted from the antenna to the chip when the reader is enquiring the tag. Therefore, the impedance of the antenna should be easily tuned for the conjugate impedance matching.

In order to be used on the metallic surface, a patch antenna is designed with the metallic surface as the antenna ground plane. For traditional patch antenna used for UHF RFID tag, a via hole or short wall is necessary for the feed line to connect the chip and the ground. Here, a double loop inductive feed structure is used for the planar antenna design. The chip is connected in the loop feed structure without any via hole or short wall. Therefore, the radiation patch and the feed structure are completely planar.

The proposed antenna is illustrated in Figure 1. The antenna is a planar radiation patch mounted on a planar metallic ground. The radiation patch printed on an FR4 substrate \((\varepsilon_r = 4.5, \tan \delta = 0.02)\) has the dimensions of \(W \times L\) \((W = 30 \text{ mm}, L = 78 \text{ mm})\). The substrate has the dimensions of \((W + 2 \text{ mm}) \times (L + 2 \text{ mm})\), which is a little larger than the radiation patch. The thickness of the antenna is \(h (h = 3 \text{ mm})\). The double loop inductive feed structure is designed in the middle of the patch. The double loop inductive feed structure has a length of \(L_{\text{loop}}\) and a width of \(W_{\text{loop}}\) \((W_{\text{loop}} = 8.2 \text{ mm})\). The feed line has a width of \(W_{\text{feed}}\) \((W_{\text{feed}} = 1 \text{ mm})\). The chip is attached in the middle of the centre arm of the double loop. The gap between the patch and the double loop is \(W_{\text{gap}}\). The parameters \(L_{\text{loop}}\) and \(W_{\text{gap}}\) are used as variables for impedance matching. By changing the length of the double loop and the width of the inductive gap, the impedance matching between the chip and the antenna could also be achieved well.

![Double loop feed planar UHF RFID tag antenna structure](image)

**Figure 1:** The double loop inductive feed planar UHF RFID tag antenna structure.
Another important consideration for the design of the antenna is the excitation of the current distribution. Figure 2 shows the current distribution comparison of the one loop inductive feed patch antenna with the double loop inductive feed patch antenna. For the conventional one loop feed patch antenna, such as Figure 2(a) shows, as there is only one loop inductive feed structure, the exciting current directions in the upper side and lower side of the radiation patch are opposite, which severely reduces the radiation performance of the antenna. Therefore, the double loop inductive feed patch antenna is proposed, such as Figure 2(b) shows. In this double loop inductive feed structure, the chip or the feed port is located in the centre of the middle arm, and the upper arm and lower arm symmetrically distribute along the upper and lower sides of the middle arm. The upper arm and the lower arm are close to the radiation patch to produce the induced current. Since the upper arm and lower arm of the double loop feed structure have the same current directions, it can be seen that the upper and lower side of the patch inductively generate the same direction coupled currents. The exciting currents on the upper and lower side of the patch are in the same direction, leading to the better antenna radiation efficiency and the improved working distance for the UHF RFID tag.

3. Simulation

The simulation and optimization of the antenna are computed by the Ansoft HFSS 12 of ANSYS, Inc. For the UHF RFID tags, most of the chips have complex impedance. The input impedance of the antenna and the chip should be conjugate matching to get the maximum energy transmission between the antenna and the chip. The impedance of the microchip used in this paper is $11 - j143\,\Omega$ (Impinj Monza 4) at 915 MHz. And as the imaginary part is much larger than the real part of the impedance, the impedance matching is mainly determined by the imaginary part matching.

For the double loop inductive feed antenna, the size (or the length) of the loop $L_{\text{loop}}$ can be used to tune the reactance of the antenna impedance. And the width of the gap $W_{\text{gap}}$ can be used to tune the inductive coupling effect, which can be used to tune the resistance of the antenna impedance. The reactance of the antenna with different double loop lengths ($L_{\text{loop}}$) is plotted in Figure 3(a), and the resistance of the antenna with different gap width ($W_{\text{gap}}$) is plotted in Figure 3(b). It shows that the reactance increases with the increase of $L_{\text{loop}}$ and the resistance decreases with the increase of $W_{\text{gap}}$. Since the frequency of the radiation patch is 915 MHz, the parameters can be optimized by the
intersections in Figures 3(a) and 3(b). So, the $L_{loop}$ is set as 47.2 mm, and the $W_{gap}$ is set as 1.6 mm. The impedance simulation of the antenna and the chip with the optimized parameters is shown in Figure 4. The resistance and the reactance of the antenna and the chip are well conjugate matching. The return loss of the antenna is plotted in Figure 5. The 3 dB bandwidth of the antenna is almost 133 Mhz and the 10 dB bandwidth of the antenna is more than 40 Mhz, which is satisfied for the UHF RFID bandwidth of USA and Europe.

The surface current of the antenna is also simulated by the HFSS. The current density on the surface (Vector $J_{surf}$ used in the HFSS) of the double loop inductive feed structure and the radiation patch of the antenna is shown in Figure 6. It is easy to see that when the phase is 0 degree or 180 degrees, the surface current direction of the middle arm of the inductive double loop and the radiation patch keeps the same. The exciting currents on the upper and lower side of the patch are always in the same direction.
4. Measurement Methods and Results

The double loop inductive feed antenna for UHF RFID tag was fabricated and tested to verify the effectiveness of the design. With the FR4 substrate and the printed circuit technology, the prototype of the antenna was fabricated with the optimized parameters. Figure 7 is the photograph of the fabricated tag mounted on a copper plate.

The performance of the tag was measured by the commercial reader Impinj Speedway revolution R420 in an anechoic chamber. The bandwidth of the reader is 902 MHz-928 MHz. The output power of the reader can be tuned from 15 dBm to 30 dBm, with a step of 0.25 dBm. The antenna of the reader is CS-771-2-R with a gain of 6 dBi. Combining the output power of the reader and the reader antenna gain, the maximum radiation power is 36 dBm (4W EIRP). The tag was mounted on a 200 mm × 200 mm copper plate and was tested by the back-scattering method [9], which is illustrated in Figure 8. The tag was placed on a rotator and the distance between the tag and the reader is fixed. By tuning the output RF power of the reader, the minimum power needed to read the tag was measured. With the minimum power, the max read range could be measured and calculated as follows:

\[ r_{\text{max}} = \frac{4^8 \text{WEIRP}}{P_{\text{min}} G_t}, \]

where \( P_{\text{min}} \) is the minimum power needed to read the tag, \( G_t \) is the gain of the antenna of the reader, \( d \) is the distance between the reader antenna and the tag, and \( L \) is the loss of the connecting cable.

The max read range is a function of frequency. Therefore, it is necessary to measure the max read range at different frequencies. By changing the RF frequency of the reader, the max read range at different frequencies could be measured and calculated. Figure 9 shows the simulation and measurement read ranges of the tag in the bandwidth of North America. The measured read range in 915 MHz is 8.8 m which are farther than the simulation results. Apart from that, most of the measured results agree quite well with the simulation results.

In Figure 10, the power bandwidth of the tag was measured and plotted. The power needed to read the tag was measured at different frequencies and was normalized with the minimum value. The minimum value is 0 dB at the frequency of 915 MHz. And the 3 dB power bandwidth covers all of the North America UHF RFID bandwidth.

The radiation patterns of the antenna could also be measured by the backscattered method. Rotate the antenna at different angles at E plan and H plan and measure the minimal read power. The radiation patterns of the antenna could be calculated by the minimal read power and the maximum read range, calculated as equation (2). In our experiments, the tag was attached on a 200 mm × 200 mm metal plane which was fixed on a rotator. The rotator was rotated every 10 degrees at the E plan or H plan, and the minimal read power was recorded. Figure 11 shows the radiation patterns of the tag on the copper plate, and the planar patch antenna has relatively good radiation patterns at both E plan and H plan.

The performance of the tag on the metallic surface was tested. The read ranges of the tag on different size metal plates are tested and shown in Table 1. From the table, the read ranges of the proposed RFID tag remain above 8 m when the size of the attached metallic surface is changed from 160 mm × 160 mm to 400 mm × 400 mm, which demonstrated the proposed antenna has good stability on different size metal plates. Note that the read range on the 400 mm × 400 mm metal plate is smaller than the 200 mm × 200 mm metal plate, which may be due to the slightly worse impedance matching detuning. Overall, the performance of the tag on different metal plates is relatively stable.

Finally, the proposed tag is compared with other antimetal tag designs, both in the literature and commercial. The comparison is listed in Table 2. Invengo-XCTF-5040-C46, Haobin-UT8957, and ZY-P8020 are three typical commercial antimetal tags used in the commercial application. These
designs are based on patch antenna or PIFA antenna solutions. Compared with the proposed design, these commercial designs have shorter read ranges [26, 27] or have a larger antenna size [28]. Two planar antimetal tags in the literature are also compared, which have similar antenna size but the read ranges are not as good as the proposed antenna [20, 24]. The proposed antimetal antenna not only has a planar structure but also has good impedance matching and radiation performance.

5. Conclusions

A type of planar UHF RFID tag patch antenna with a double loop inductive feed structure is proposed for the metallic surface application. The inductive feed structure with the double loop enhances the coherence of the current direction on the metal surface, leading to a better radiation performance without short via holes or short walls. At the same time, the impedance matching is much more flexible than other planar tag antennas used on the surfaces of metal objects. It also has merits of small size, uncomplicated structure, and long reading distance. Moreover, the proposed antenna could be fabricated in mass production at low cost.

Figure 8: The back-scattering measurement setup.

Figure 9: Theoretical and experimental read ranges of different frequencies for the tag antenna (EIRP = 4 W).

Figure 10: Power bandwidth of the tag antenna.
with printing technology such as conductive silver paste or conductive ink printing.

**Data Availability**

The data used to support the findings of this study are available from the corresponding author upon request.

**Conflicts of Interest**

The authors declare that there is no conflict of interest regarding the publication of this paper.

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