Design and Miniaturization of an RFID Tag Using a Simple Rectangular Patch Antenna for Metallic Object Identification

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1 Introduction

Radio Frequency Identification (RFID) is a technology used for object identification by means of radio waves. A basic RFID system will usually consists of: RFID tags for attaching to the objects to be identified, at least one RFID reader with a reader antenna connected to it for communication with the tags, and usually a host computer or network system for data handling [1]. In recent years, passive UHF (860-960 MHz) RFID systems are receiving increasing attention due to some of their attractive features such as good read ranges and high data rates. However, when the tagging of metallic objects is involved, the RFID system will suffer from a degradation in performance. This is either due to the detuning of the resonant frequency of the RFID tag or insufficient amount of the required interrogation field from the RFID reader antenna reaching the tag near the metallic surface. Hence, analysis and research on the tagging of metallic objects are required to improve the performance and reliability of the system.

Research in RFID systems involving metallic objects and structures is still in an early stage. However, over the past few years, some passive UHF RFID tags suitable for tagging metallic objects have been developed. These tags are mainly made of antennas that require a ground plane to operate. Some examples are tags made of patch antennas and planar inverted-F antennas [2–4].

Maintaining the simplicity of the tag design is always a benefit. In this paper, we will present a passive RFID tag suitable for metallic object identification that consists of a rectangular patch antenna with a simple impedance matching method to match the tag antenna and chip impedances. Beside a simple tag design, it is also a benefit to have a small RFID tag size for the reason of cost reduction and the feasibility of attaching the tag to smaller metallic items. Hence, we will also present an analysis of the reduction of the size of the tag antenna design above and the possible effect towards the read range performance caused by the reduction.

2 The RFID Tag Design

A basic RFID tag consists of an antenna and an RFID chip. If the tag antenna and chip impedances are not conjugately matched, some form of impedance matching method will usually be included in the tag design to match the tag antenna and chip impedances in order to obtain a maximum power transfer.

The tag presented in this paper is designed to operate in the Australia UHF RFID band that spans 920 - 926 MHz. Hence, the target frequency used for the design

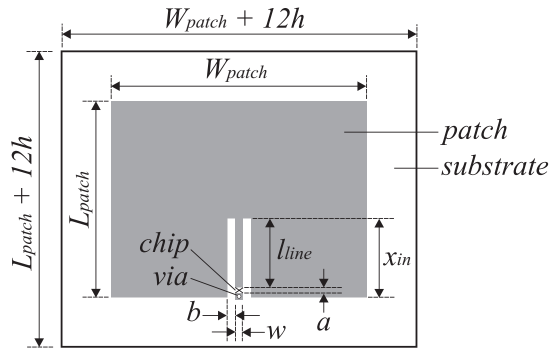

Figure 1: Structure of the RFID tag antenna (Top view).

calculations is 923 MHz. The tag antenna used is a regular rectangular patch antenna. It is designed for implementation on a double-sided copper clad FR4 board with substrate thickness $h = 1.6$ mm and relative dielectric permittivity $\varepsilon_r = 4.4$. Using the method in [5], for the antenna to resonate at 923 MHz, it is calculated that the patch has length $L_{patch} = 77$ mm and width $W_{patch} = 99$ mm. The ground plane size of the patch antenna is $6h$ longer on each side compared to the size of the patch. The RFID tag is as shown in Figure 1.

The RFID tag chip used in the design can be represented by an equivalence of a resistor with resistance R_{chip} and a capacitor with capacitance C_{chip} in parallel. The values of $R_{chip} = 1$ kΩ and $C_{chip} = 1.2$ pF are used in the design. Based on these values, the equivalent impedance of the chip at 923 MHz is $20 - j141$ Ω.

To obtain maximum power transfer, an impedance matching method using a microstrip line has been used in this design. The idea is to use an inset feed method and adjust the inset distance x_{in} to obtain an impedance value such that when this impedance is transformed using a certain length l_{line} of the microstrip line, the transformed impedance corresponds to the conjugate of the tag chip impedance mentioned above. We have chosen to use a microstrip line with characteristic impedance of 50 Ω. The reason is that 50 Ω gives a microstrip line with width w that is neither too wide nor too thin and hence suitable for attaching the RFID chip. In addition, 50 Ω is within the valid characteristic impedance range for a microstrip line as discussed in [6]. From calculations, we have $w = 3$ mm.

The design is simulated using Ansoft HFSS. Using simulations, the inset distance and microstrip line length are determined, that is, $x_{in} = 36$ mm and $l_{line} = 32$ mm. The length of the patch is adjusted slightly for resonance at 923 MHz giving $L_{patch} =$ 76 mm. The patch width remains the same at $W_{patch} = 99$ mm. The distance b between the microstrip line and the patch is fixed to 3 mm. A small square area (3 mm $\times$ 3 mm) connected to the ground plane through a via is located at the end of the microstrip line. The tag chip is placed across the gap ($a = 2$ mm) between the small square area and the microstrip line. From simulations, a total impedance of $17 + j144$ Ω at 923 MHz is obtained for the antenna structure, which is close enough for a conjugate match with the tag chip impedance. The tag antenna structure is then simulated on a $1.5\lambda \times 1.5\lambda$ aluminium metallic plane and the simulation results shows that the impedance remains almost the same as the case without the metallic plane.

The tag antenna is fabricated and a practical read range measurement is carried out. An RFID reader (Model ALR-9780-EA) suitable for operation in Australia is used in the measurement. The RFID reader antenna used has a 6 dBi gain and the total radiated power from the antenna is 4 W EIRP. The tag is placed on a $1.5\lambda \times 1.5\lambda$ aluminium metallic plane and with the reader antenna radiating at normal incidence to the metallic plane, the read range measured is 1.44 m.

3 RFID Tag Size Reduction

With a simple RFID tag for metallic surfaces designed, our next aim is to reduce the size of the tag antenna to find the smallest possible size while still offering acceptable read range performance. For patch antennas, there are many ways such as those discussed in [7] to reduce the size of the antenna. One example that can possibly be used is the use of substrate with higher dielectric permittivity. However, this may increase the cost of the RFID tag. Maintaining a low RFID tag cost is desirable so that it is more cost effective to tag objects at item-level in the supply chain. Hence, we have reduced the size of the tag by reducing the patch width W_{patch} of the tag antenna. The patch length L_{patch} remains the same and the same low-cost FR4 material as above has been used.

An analysis on reducing W_{patch} has been performed. W_{patch} is reduced slowly, at steps of 10 mm, from 99 mm (original full size) to 19 mm. The antenna ground plane size is reduced accordingly to the patch size. The tag antenna corresponding to each size is simulated using HFSS. The simulation results show that the antenna impedance increases as W_{patch} reduces. It is also found from the simulations that the resonant frequency of the tag antenna has increased slightly as W_{patch} is reduced. All these causes the total input impedance of the tag antenna structure to change. Hence, in order to maintain a total input impedance that is the conjugate of the tag chip impedance, the inset distance x_{in} and the microstrip line length l_{line} are adjusted slightly for each case. After the adjustment of x_{in} and l_{line}, the antenna structure is simulated on a $1.5\lambda \times 1.5\lambda$ aluminium metallic plane to make sure that the antenna impedance is almost the same as when without the metallic plane.

RFID tags corresponding to different patch widths were fabricated. Read range measurements of these tags are performed using the same RFID reader and reader antenna mentioned above. The plot of read range versus W_{patch} is shown in Figure 2 for the tag in free space and when the tag is attached to a $1.5\lambda \times 1.5\lambda$ aluminium metallic plane. It can be observed from Figure 2 a pattern in the reduction of read range when W_{patch} is reduced. The read range of the smallest size tag (with $W_{patch} = 19$ mm) is about half that of the full size tag (with $W_{patch} = 99$ mm). However, despite the read range reduction, the read range for the smallest tag is still acceptable considering the amount of tag size reduction compared to the full size tag. Hence, the smaller tag can be suitable for use in applications that do not require a maximum possible read range but do require a smaller tag size in order to attach the tag to a limited space or area on the metallic object.

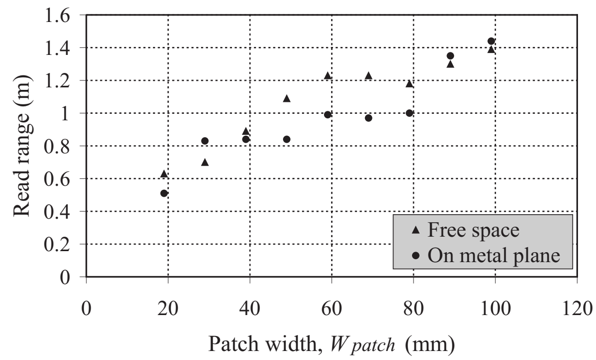

Figure 2: Practical read range measurement results for tag in free space and tag attached to metallic plane.

4 Conclusion

This paper has presented a passive RFID tag that consists of a rectangular patch antenna, with a simple impedance matching method, that is suitable for tagging metallic objects. The tag design has been implemented and tested, and a satisfactory read range performance is obtained when the tag is attached to a metallic structure. An analysis of the reduction of the tag antenna size (reduction of patch width) and the effect on the read range performance has also been presented. Analysis results have shown that there is a trade-of between having a smaller antenna and the read range performance. Depending on the type of application, if the read range requirement is lower, a smaller tag will be beneficial in terms of cost and the ease of attaching the tag to smaller metallic objects.

5 References

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