Circular folded dipole antenna for RFID tag on metallic cylinder

Naobumi Michishita¹,a), Luong Anh Tuan¹, Takahiro Hashimoto¹, Hisashi Morishita¹, and Takayuki Koshi²
¹ Department of Electrical and Electronic Engineering, National Defense Academy, 1–10–20 Hashirimizu, Yokosuka, Kanagawa, 239–8686 Japan
² Komatsu Ltd., 2–3–6 Akasaka, Minato-ku, Tokyo, 107–8414 Japan
a) naobumi@m.ieice.org

Abstract: The use of ultra-high frequency radio frequency identification (RFID) technology has recently been studied for the wireless management of consumable parts in automobiles. The RFID tag antennas attached to the consumable parts in an engine room, which is a closed metal space, require horizontal polarization and omnidirectional radiation characteristics. This paper presents the design results of a circular folded dipole antenna for an RFID tag on a metallic cylinder.

Keywords: radio-frequency identification, circular folded dipole antenna, metallic cylinder, omnidirectional pattern

Classification: Antennas and Propagation

References

[1] Y. Tarusawa, S. Nishiki, and T. Nojima, “Fine positioning three-dimensional electric-field measurements in automotive environments,” IEEE Trans. Veh. Technol., vol. 56, no. 3, pp. 1295–1306, May 2007. DOI: 10.1109/TVT.2006.895540
[2] 920 MHz-band RFID equipment for specified low power radio station, ARIB STD-T107, Ver.1.1, Oct. 2017.
[3] S. Horiuchi, K. Yamada, S. Tanaka, Y. Yamada, and N. Michishita, “Comparisons of simulated and measured electric field distributions in a cabin of a simplified scale car model,” IEICE Trans. Commun., vol. E90-B, no. 9, pp. 2408–2415, Sept. 2007. DOI: 10.1093/ietcom/e90-b.9.2408
[4] S. Fukui, M. Mizoguchi, Y. Fukagawa, S. Kouno, and N. Maeda, “Analysis of electromagnetic wave propagation by using Poynting vector in automobile,” Int. Conf. Electromagn. Adv. Appl., Torino, Italy, pp. 1111–1114, Sept. 2013. DOI: 10.1109/iceaa.2013.6632415
[5] S. Kitazawa, H. Kamoda, S. Ano, N. Kukutsu, and K. Kobayashi, “A study of realization of wireless harness for automobile,” IEICE Technical Report, SAT2014-30, pp. 27–32, Aug. 2014 (in Japanese).
[6] S.-Y. Chen and P. Hsu, “CPW-fed folded-slot antenna for 5.8 GHz RFID tags,” Electron. Lett., vol. 40, no. 24, pp. 1516–1517, Nov. 2004. DOI: 10.1049/el:20046780
[7] G. Marrocco, “Gain-optimized self-resonant meander line antennas for RFID applications,” IEEE Antennas Wireless Propag. Lett., vol. 2, pp. 302–305, 2003. DOI: 10.1109/LAWP.2003.822198
1 Introduction

The use of ultra-high frequency radio frequency identification (RFID) technology has recently been studied for the wireless management of consumable parts in automobiles [1]. The standard of the frequency range is from 916.7 MHz to 923.5 MHz in Japan [2]. The electromagnetic environments inside and outside a car have also been investigated [3, 4]. The evaluation of the radio wave propagation in the engine room and outside a vehicle from the engine room achieved a short-range wireless sensor network on the car engine room with narrow and complicate spaces [5].

Various RFID tag antennas, such as a folded slot antenna [6], meander line antenna [7], planar inverted-F antenna [8], and microstrip antenna [9, 10] have been proposed. A consumable part, such as the oil filter, is rotated and inserted into the engine. Thus, the conventional RFID tag antenna installed on the side surface of the cylinder has a directional pattern. As a result, an angle obstructs the communication. Therefore, omnidirectional radiation characteristics are required for the working of the RFID tag antenna. In addition, the appropriate configuration for the RFID tag antennas attached to consumable parts in an engine room, which is a closed metal space, has been examined [11]. If the RFID reader antenna is installed on the wall of the engine room, a horizontal polarization is suitable for the RFID reader and tag antennas. This paper presents the design results of a circular folded dipole antenna for the RFID tag on a metallic cylinder as a typical consumable part in the engine room.

2 Configuration of proposed antenna

The configuration of the proposed circular folded dipole antenna on a metallic cylinder is shown in Fig. 1. The initial structure was the circular plate on the top of the cylinder. The characteristic mode of the circular plate with the cylinder was analyzed. As a result, the circular folded dipole configuration was obtained. The circular configuration of the antenna provides a quasi-omnidirectional pattern. However, based on the image theory, the input impedance decreases because the current source is placed on the reflector. To overcome the impedance reduction, the
step up of the impedance by the principle of the folded dipole antenna was employed. For practical use, the dielectric thin sheet will be used as the spacer. However, the air space was employed to show the basic concept of the proposed antenna.

The antenna was mounted on the top of the metallic cylinder with a radius $r_b$ and height $h$. The antenna was modeled as a copper conductor sheet with a thickness of 0.3 mm. The feeding port was arranged at the center of the inner conductor. The designed parameters for achieving conjugate matching to the chip impedance are as follows: radius of the antenna $r_a$, gap between the antennas $l$, and width of the outer conductor $w$. The distance between the antenna and the top surface of the metallic cylinder $d = 10$ mm, the width of the inner conductor $w_1 = 1$ mm and the space between the inner and outer conductors $g = 1$ mm were fixed.

### 3 Design of input impedance characteristics

The input impedance of the Impinj Monza 6-P tag chip was approximately $12 - j119 \ \Omega$ at an operating frequency of 920 MHz [12]. Therefore, the input impedance of the circular folded dipole antenna on the metallic cylinder must be equal to the complex conjugating impedance of the IC, i.e., $12 + j119 \ \Omega$ for matching the impedance. First, the initial values of $l$, $w$, and $r_a$ are 10 mm, 1 mm and 30 mm, respectively. In this case, the length of the inner conductor corresponds to the half wavelength at 920 MHz. The initial value of the input impedance is $5.4 + j190.0 \ \Omega$. As $l$ increased as shown in Fig. 2(a), the reactance value decreased while the variation of the resistance value was small. The input impedance with $l = 20$ mm is $5.0 + j32.4 \ \Omega$. Next, the step up of the impedance is examined, when $l = 20$ mm and $r_a = 30$ mm. As $w$ increased as shown in Fig. 2(b), the resistance value increased while the reactance value decreased. The input impedance with $w = 5$ mm is $12.1 - j226.6 \ \Omega$. And, the effect of $r_a$ is examined, when $l = 20$ mm and $w = 5$ mm. As $r_a$ increased as shown in Fig. 2(c), the reactance value increased while the variation of the resistance value was small. The input impedance with $l = 20$ mm, $w = 5$ mm, and $r_a = 32$ mm is $11.4 + j105.0 \ \Omega$. Finally, the impedance at different size of the metallic cylinder is examined. When $h$ was varied, the impedance characteristics
was not affected. Figure 2(d) shows the input impedance characteristics when $r_b$ was varied and $h$ of 165 mm was fixed. Since the parameter $r_b$ only affected resistance values, the parameter $w$ should be redesigned when $r_b$ is varied.

4 Experiment

Next, prototype of the antenna as shown in Fig. 1 was fabricated as shown in Fig. 3(a). The antenna with the metallic cylinder was measured. The antenna without the metallic cylinder was also simulated. Figs. 3(b) and (c) show the measured results of the $|S_{11}|$ and input impedance characteristics. The input impedance was measured through the 50 Ω coaxial cable with Spertopf balun. Since the standard 50 Ω system was employed, the $|S_{11}|$ value became high due to the conjugate matching of the input impedance of the antenna for the chip impedance. Since the measured results agreed with the simulated results at 920 MHz, the validity of the simulation was verified. In addition, the antenna without the cylinder has high impedance characteristic. Fig. 3(d) shows the radiation patterns at 920 MHz on $xy$ plane.

The radiation pattern was measured in the anechoic chamber, and the equipment of the signal generator and spectrum analyzer was used. The actual gain including mismatch loss to the 50 Ω was plotted. The simulated and measured results were in good agreement. The horizontal polarization of $E_\phi$ component for both simulated and measured results were almost omnidirectional on the horizontal plane. The gain and circularity were improved in comparison with the antenna without the metallic cylinder. The antenna gain was $-10$ dBi as shown in Fig. 3(d). However, the gain without mismatch loss to the 50 Ω became $-0.1$ dBi, because the conjugate matching was achieved to the chip impedance as shown in Fig. 3(c). From the standard in [2],
Fig. 3. (a) Prototype of antenna on metallic cylinder. The parameters are $l = 18$ mm, $w = 6$ mm, and $r_a = 32.2$ mm. Simulated and measured results of (b) $|S_{11}|$, (c) input impedance, and (d) radiation patterns on $xy$ plane.

the absolute gain should be 3 dBi or less. The gain of the proposed antenna satisfied the application of low power radio station. When the general tags using a microstrip antenna was installed on the side of the metallic cylinder, the gain difference in the horizontal plane became 8.0 dB [9, 10]. Therefore, the improvement of 5.7 dB for circularity can be achieved by using the proposed antenna.

5 Conclusion

This study proposed a circular folded dipole antenna for the RFID tag on a metallic cylinder. The antenna was designed to achieve conjugate matching to the chip impedance. The horizontal polarization and omnidirectional radiation characteristics were also obtained. The simulation was verified through an experiment.