Circularly Polarized RFID Tag Antenna Design for Underground Localization System

Yiming Chen
yimingchen@mymail.mines.edu

Atef Z. Elsherbeni
aelsherb@mines.edu

Department of Electrical Engineering
Colorado School of Mines
Golden, CO, USA

***Abstract*—A circularly polarized antenna is proposed in this paper for a Radio frequency identification tag to be used in the underground localization system. The tag supports wideband performance around 915 MHz and the fully covered metal ground makes the tag less affected by the medium it will be attached to. An extended metal plate is also discussed to improve the tag read range and to make it easier to attach on the uneven wall in underground tunnels. With the extended metal plate, the tag -10 dB reflection-coefficient bandwidth is 37 MHz (890-926 MHz) and the 3 dB AR bandwidth is 6.4 MHz (911.4-917.8 MHz). This design provides good circular polarization characteristics and a read range of 2.2 m.**

I. Introduction

Radio frequency identification (RFID) is a popular and low-cost technology for detecting and identifying objects. In this paper we design a tag for an inverse localization system operating at the center frequency of the RFID United States allocated frequency range from 902 MHz to 928 MHz [1].

Based on the back-scattering working principle, the conjugated impedance matching between the tag and embedded chip varying with frequency is the first challenge in the passive chipped tag design. Secondly, to improve the communications between the tag and the RFID system reader, it is intended to design a circularly polarized (CP) tag and a CP antenna connected to the reader [2]. Similar challenges related to the tag geometry and the impedance matching between tag and embedded chip are reported in [3]–[6]. Another challenge is that the complex properties of mediums where the tag will be mounted on could break the optimized impedance matching, so the read range will be greatly reduced, thus the use of an optimized tag design with the presence of a fully metal ground is preferred in order to enhance the tag read range [5], [6].

In this research project, a CP tag with extended metal plate working at centered 915 MHz band is optimized to communicate with the CP reader antenna while maintaining at least 2 m read range inside tunnels. The metal plate will not only avoid impedance mismatch, but also make the read range of this CP tag sufficient for the width of underground tunnel even when the gain of reader antenna is in the order of 2 dB.

II. Antenna Design

The design parameters related to the CP tag with and without the extended metal plate are illustrated as Fig. 1, in which the

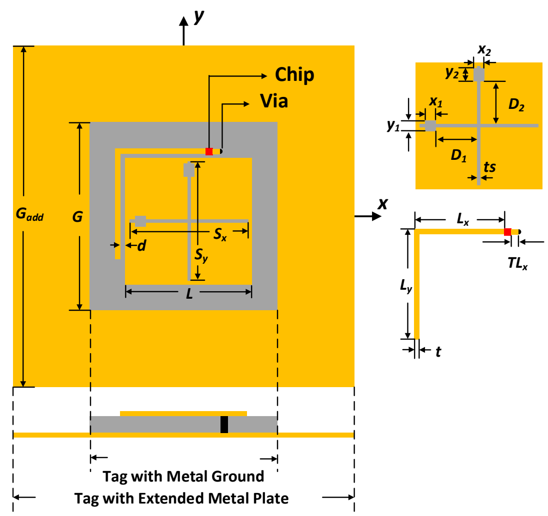

Fig. 1. Schematic model of the CP tag with and without extended metal plate

shorting pin 'Via' connects the microstrip line and the ground for additional capacitive coupling. The slotted square patch and the L-shaped line are simulated using the low-cost material FR4 substrate shown in gray color with thickness of 1.6 mm and relative permittivity of 4.4 and loss tangent of 0.02. The CP tag is optimized to yield lower reflection coefficient (S_{11}) and good axial ratio (AR) at the centered 915 MHz band while considering the conjugated impedance matching with the commercial chip Alien Higgs-4 RFID IC [7] shown in the figure as 'Chip'. After optimization in the full wave simulation software HFSS [8], the dimensions in millimeters of the CP tag without extended metal plate are: $G = 70$, $G_{add} = 0$, $d = 3$, $D_1 = 16.1$, $D_2 = 12.6$, $L = 49.5$, $L_x = 35.2$, $L_y = 44.2$, $S_x = 43.5$, $S_y = 41.8$, $t = 1.6$, $TL_x = 2.6$, $ts = 1$, $x_1 = 4.1$, $x_2 = 4.7$, $y_1 = 4.4$, $y_2 = 4.9$, while for the tag with extended metal plate are: $G = 70$, $G_{add} = 200$, d = 2.3, $D_1 = 14.8$, $D_2 = 16.7$, $L = 49.3$, $L_x = 33.3$, $L_y = 47.9$, $S_x = 42.9$, $S_y = 43.2$, $t = 1.6$, $TL_x = 2.7$, $ts = 0.9$, $x_1 = 3.5$, $x_2 = 3.6$, $y_1 = 4.4$, $y_2 = 4.9$.

III. Simulation Results

Fig. 2 shows the -10 dB S_{11} bandwidth for the tag without extended metal plate as the blue dash line from 902 to 939 MHz and that for the tag with 200 mm × 200 mm plate as the black solid line from 890 to 926 MHz. The simulated AR in the boresight direction ($\theta = 0^{\circ}$, $\varphi = 0^{\circ}$) versus frequency are shown in Fig. 3. The AR value is 1.26 dB and 0.4 dB at 915 MHz for the tag without and with extended plate, respectively. The 3dB AR bandwidth is from 913.2 to 919 MHz (5.8 MHz) for the tag without extended metal plate and from 911.4 to 917.8 MHz (6.4 MHz) with the extended plate. The results of S_{11} and AR indicate that the tag with 200 mm × 200 mm plate is better than the tag with 70 mm × 70 mm plate, while keeping the same foot-print size of the substrate.

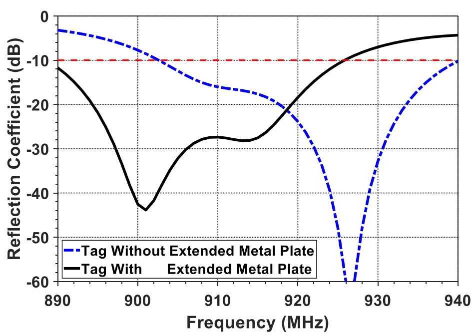

Fig. 2. Simulated S_{11} for the CP tag antenna with and without extended metal plate.

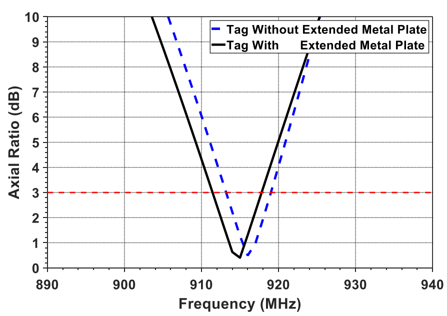

Fig. 3. Simulated axial ratio for the CP tag antenna with and without extended metal plate.

Figure 4 presents the far-field gain of the optimized tag, in which the gain is -15.95 dBic and -9.24 dBic at 915 MHz for the tag without and with extended metal plate. Finally, to predict the actual read range, the maximum value is calculated by considering the Friis formula as denoted below:

$$r_{\max} = \frac{\lambda_0}{4\pi}\sqrt{\frac{P_t G_t G_r \rho(1-|\Gamma|^2)}{P_{th}}} \quad (1)$$

where λ_0 is the wavelength at 915 MHz; G_r is the reader antenna gain with the value of 2 dB; G_t is the gain of tag antenna; Γ is the reflection coefficient; the polarization factor ρ is 1 due to the same handedness for tag and reader antenna; the output power (P_t) of the reader is 30 dBm; the chip's sensitivity (P_{th}) is -16 dBm, all in all, the theoretical maximum read range ($r_{\max}$) at 915 MHz can be calculated as 1.0 m and 2.2 m for the tag without and with extended metal plate. This 2.2 m read range makes the tag antenna with 200 mm × 200 mm metal plate suitable to install in the 4 m wide mine tunnels for RFID localization system.

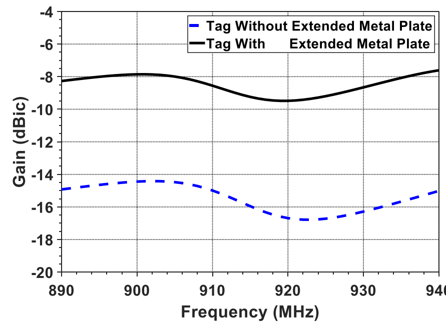

Fig. 4. Simulated gain for the CP tag antenna with and without extended metal plate.

IV. Conclusion

The designed circularly polarized tag with extended metal plate yields a -10 dB S_{11} bandwidth coving the US RFID band as well an axial-ratio bandwidth of 6.4. MHz (from 911.4 to 917.8 MHz). There is also a significant increase in the tag read range from 1 to 2.2 m with only 2dB gain of the reader antenna. As a result, the reader antenna could have a smaller occupied volume and longer standby time which will make it easier to integrate with other devices. Future work is focused on the fabrication and testing of the simulated tag antenna.

Acknowledgement

This research has been funded in part by grants from the Alpha Foundation for Improving Mine Safety and Health, grant number AFC820-50, and CDC NIOSH, contract No. 75D30119C05412.

References

[1] K. V. S. Rao, P. V. Nikitin, and S. F. Lam, "Antenna design for UHF RFID tags: A review and a practical application," IEEE Trans. Antennas Propag, vol. 53, pp. 3870–3876, December 2005.

[2] C. A. Balanis, Antenna Theory: Analysis and Design, 4th ed, John wiley & sons, 2016, pp. 66–75.

[3] T. Bjorninen, L. Ukkonen, L. Sydanheimo, and A. Z. Elsherbeni, "Circularly polarized tag antenna for UHF RFID," In Proc. 26th Annu. Rev. Prog. Appl. Comput. Electromagn, pp. 372–375, 2010.

[4] J. H. Lu, and B. S. Chang, "Planar compact square-ring tag antenna with circular polarization for UHF RFID applications," IEEE Trans. Antennas Propag, vol. 65, pp. 432–441, February 2017.

[5] H. D. Chen, S. H. Kuo, and C. H. Tsai, "Coupling-feed circularly polarized RFID tag antenna mountable on metallic surface," IEEE Trans. Antennas Propag, vol. 60, pp. 2166–2174, May 2012.

[6] H. D. Chen, and S. H. Kuo, "Compact broadband dual coupling-feed circularly polarized RFID microstrip tag antenna mountable on metallic surface," IEEE Trans. Antennas Propag, vol. 60, pp. 5571–5577, December 2012.

[7] https://www.alientechnology.com/products/ic/higgs-4/

[8] Ansys, HFSS, "3D electromagnetic field simulator for RF and wireless design." Internet: https://www. ansys. com/products/electronics/ansys-hfss, April, 2019.