

COMPACT UHF RFID TAG ANTENNA WITH MONZA 4 CHIP FOR STABLE METALLIC SURFACE APPLICATIONS

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ARTICLE INFO	ABSTRACT
Received: 06/10/2025 Revised: 13/4/2026 Published: 14/4/2026	This paper presents the design, simulation, and experimental validation of a compact UHF RFID tag antenna specifically optimized for metallic surface applications. The antenna employs a Monza 4 RFID chip, which has an input impedance of $7.4 - j74.5 \Omega$ at 915 MHz. The antenna geometry was meticulously optimized to achieve precise conjugate impedance matching with the chip, enabling an exceptionally high power transmission coefficient (PTC) of approximately 99%. The fabricated prototype demonstrates a stable reading distance exceeding 7.3 m under a reader effective isotropic radiated power (EIRP) of 4.0 W, confirming efficient energy coupling and robust tag performance. Experimental evaluations were conducted by attaching the tag at the center of several metallic surfaces, with results consistently indicating stable impedance characteristics and reliable read capability. Owing to its simple configuration, low-profile structure, and cost-effective fabrication, the proposed antenna provides a practical and durable solution for UHF RFID tagging in harsh metallic environments.
KEYWORDS	
Metal tag antenna	
RFID chip	
Impedance matching	
RFID tag antenna	
Meander-line patch	

THIẾT KẾ ANTEN THẺ RFID UHF GỌN NHỎ TÍCH HỢP CHIP MONZA 4 CHO MÔI TRƯỜNG KIM LOẠI ỔN ĐỊNH

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THÔNG TIN BÀI BÁO	TÓM TẮT
Ngày nhận bài: 06/10/2025 Ngày hoàn thiện: 13/4/2026 Ngày đăng: 14/4/2026	Bài báo này trình bày quá trình thiết kế, mô phỏng và kiểm chứng thực nghiệm của một ăng-ten thẻ RFID UHF nhỏ gọn, được tối ưu đặc biệt cho các ứng dụng trên bề mặt kim loại. Ăng-ten sử dụng chip RFID Monza 4, có trở kháng đầu vào là $7,4 - j74,5 \Omega$ tại 915 MHz. Cấu trúc của ăng-ten được tối ưu cẩn thận nhằm đạt được ghép nối trở kháng liên hợp chính xác với chip, giúp đạt hệ số truyền công suất (PTC) rất cao, khoảng 99%. Mẫu ăng-ten được chế tạo cho thấy khoảng cách đọc ổn định lớn hơn 7,3 m dưới công suất bức xạ đẳng hướng hiệu dụng (EIRP) của đầu đọc là 4,0 W, chứng minh khả năng truyền năng lượng hiệu quả và hoạt động ổn định. Các thí nghiệm được thực hiện khi gắn thẻ lên nhiều bề mặt kim loại khác nhau, cho thấy đặc tính trở kháng ổn định và khả năng đọc đáng tin cậy. Nhờ có cấu trúc đơn giản, độ mỏng thấp và quy trình chế tạo tiết kiệm chi phí, ăng-ten được đề xuất mang lại giải pháp thực tiễn và bền vững cho ứng dụng RFID UHF trong môi trường kim loại khắc nghiệt.
TỪ KHÓA	
Thẻ Tag trên kim loại	
Chip RFID	
Phối hợp trở kháng	
Thẻ RFID	
Patch dạng gấp khúc	

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1. Introduction

Radio frequency identification (RFID) has become an indispensable technology in modern communication and information systems. It plays a vital role in diverse applications such as electronic toll collection, logistics and distribution management, supply chain tracking, healthcare monitoring, access control, and the rapidly growing Internet of Things (IoT) [1], [2]. Among different RFID technologies, passive tags operating in the ultrahigh frequency (UHF) band are of particular interest. Compared with their low-frequency (LF) and high-frequency (HF) counterparts, UHF RFID tags can provide longer communication ranges, higher data transfer rates, and greater potential for large-scale, cost-effective deployment [3], [4]. These advantages make UHF RFID systems attractive for both industrial and consumer-level applications.

Despite their advantages, one of the most critical challenges in UHF RFID deployment is the significant degradation in tag antenna performance when tags are mounted on metallic surfaces. The presence of a conductive backing alters the near-field distribution, which in turn shifts the resonant frequency, reduces the input impedance match, decreases the power transmission coefficient (PTC), and distorts the radiation pattern. This leads to shorter reading distances and unreliable tag operation, which restricts the practical use of RFID in metallic environments such as containers, vehicles, pipelines, or metallic shelves.

Over the past two decades, many researchers have proposed techniques to mitigate these issues. One widely studied method is the use of artificial magnetic conductors (AMCs) or electromagnetic bandgap (EBG) structures, which can suppress surface currents and improve radiation efficiency [5] – [8]. While AMC-based designs can enhance gain and radiation stability, they often require multilayer structures or large unit cells, which increase antenna thickness, fabrication cost, and complexity. Another common solution is the planar inverted-F antenna (PIFA) [9], [10], which employs high-impedance surfaces to reduce detuning from metallic placement. However, conjugate impedance matching between the antenna and the integrated circuit (IC) remains difficult, as most commercial RFID ICs have high quality factors, narrow bandwidths, and highly capacitive input impedances [11] – [13].

Several impedance-matching strategies have been investigated to address this issue. Techniques such as loading bars, tuning slots, and conductive sheets have been used [14], [15], but they often come at the cost of lower radiation efficiency. Via-loaded patch designs [16], [17] can improve performance, yet they strongly depend on via placement and feed-point configuration, making design optimization and fabrication more challenging. Folded patch antennas have also been introduced [18] – [22], where the antenna size is reduced by splitting or folding the radiating patch. Although these approaches improve compactness, they typically require additional layers or ground planes, and in some cases, the use of adhesive bonding materials introduces long-term reliability problems due to surface oxidation. In light of these limitations, there remains a strong need for compact, structurally simple, and cost-effective RFID tag antenna designs that maintain reliable performance when mounted on metallic surfaces.

In this work, we present a novel compact UHF RFID tag antenna optimized for metallic environments and designed to operate with the Monza 4 IC chip, which has an input impedance of $7.4 - j74.5 \Omega$ at 915 MHz. The proposed structure introduces a shorting pin mechanism integrated into a symmetric dual-arm configuration. The shorting pins play a critical role in tuning the input impedance and compensating for the capacitive nature of the Monza 4 chip, while also suppressing detrimental surface currents induced by the metallic backing. By carefully optimizing the antenna geometry and the location of the shorting pins, efficient conjugate impedance matching is achieved, resulting in a power transmission coefficient of nearly 99%.

2. Materials and Methods

The proposed UHF RFID tag antenna was fabricated on a low-cost FR4 substrate ($\epsilon_r = 4.4$, loss tangent = 0.02) with dimensions $50 \times 50 \times 0.8 \text{ mm}^3$. It operates in the FCC UHF RFID band (902–928 MHz) and is optimized for the Monza 4 chip ($7.4 - j74.5 \Omega$ at 915 MHz) [23]. As shown in Fig. 1a, the antenna adopts a symmetric dual-loop structure with inner slots to extend current paths and maintain compactness. A feed gap at the center holds the chip, while shorting pins between the radiating arms and ground plane tune impedance and enhance stability on metallic surfaces. The antenna was fabricated using standard photolithography and etching on copper-clad FR4 (see Figure 1b). The final prototype is compact, low-profile, and mechanically robust, well suited for metal-mounted UHF RFID applications. The optimized parameters of the proposed tag antenna and the list of terms are shown in Table 1 and Table 2, respectively.

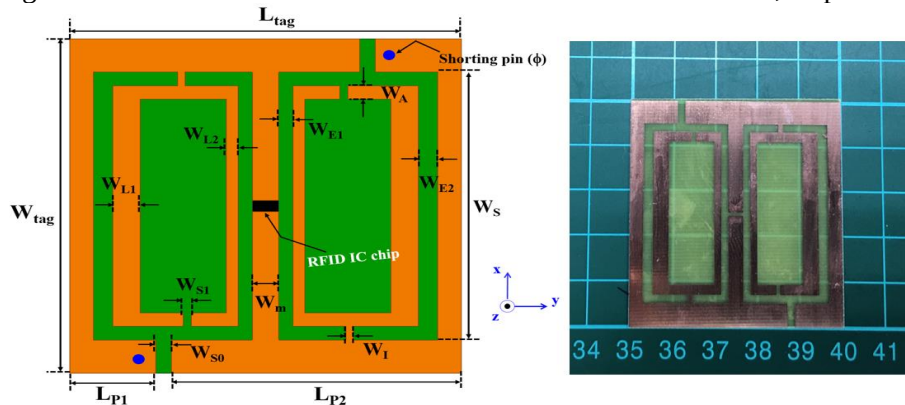


Figure 1. Structural overview of the proposed antenna on the metallic platform with (a) geometry configuration and (b) fabricated model

Table 1. The designed structural parameters for antenna optimization

Parameters	Dimension (mm)	Parameters	Dimension (mm)	Parameters	Dimension (mm)
W_{tag}	50	W_{S1}	1.0	W_m	3.4
L_{tag}	50	W_{L2}	1.5	W_{E2}	2
W_{L1}	5	W_A	2	W_I	0.9
W_{S0}	4	W_{E1}	1.8	W_S	40
L_{P1}	11	L_{P2}	36	ϕ	0.7

Table 2. Glossary of Symbols and Terms

Symbol	Definition
Z_{IC}	IC chip input impedance
Z_{ant}	Antenna input impedance
PTC	Power Transmission Coefficient
RL	Power wave reflection coefficient
EIRP	Effective isotropic radiated power

The proposed UHF RFID tag antenna was designed through a step-by-step optimization to achieve conjugate impedance matching with the Monza 4 chip ($7.4 - j74.5 \Omega$ at 915 MHz). The initial rectangular loop structure resonated far above the target frequency, as displayed in Figure 2a. Introducing a single-loop increased the current path, reducing the resonance toward the UHF band, as revealed in Figure 2b. A dual-loop configuration was then adopted to extend electrical length and improve current symmetry, enhancing stability on metallic surfaces (see Figure 2c). Finally, tunable slot widths (W_{S1}) and shorting pins were incorporated to fine-tune both resistive and reactive components, yielding precise impedance control (see Figure 2d). The simulated impedance of the optimized antenna, shown in Figure 3a, confirms accurate matching with the Monza 4 chip.

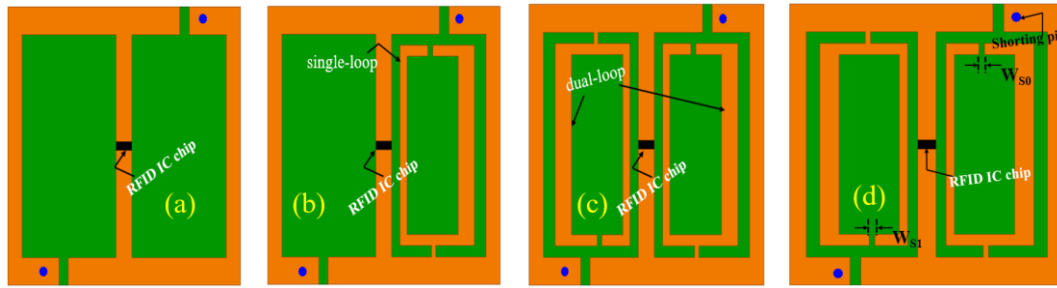


Figure 2. Design Procedure of the proposed tag antenna with (a) without loop, (b) single loop, (c) dual-loop and (d) dual-loop and tunable slot

Figure 3b shows the simulated surface current distribution of the proposed tag antenna at 915 MHz. The current is mainly concentrated in the dual-loop structure, especially near the feed region and inner loop edges, confirming efficient excitation of the resonant mode. The shunting pin and tuning slots guide the current symmetrically, improving radiation and minimizing detuning on metallic surfaces. Figure 3c presents the simulated radiation efficiency and gain within 800–1000 MHz. The antenna achieves about 26% efficiency near 930 MHz and a peak gain of -2.4 dB, both stable across the UHF RFID band. Although the gain is moderate, it is typical for compact on-metal RFID tags. The combination of stable gain and acceptable efficiency ensures reliable tag-reader communication, supporting a measured read range beyond 7.3 m under 4 W EIRP. These results confirm the effectiveness and practicality of the proposed antenna design.

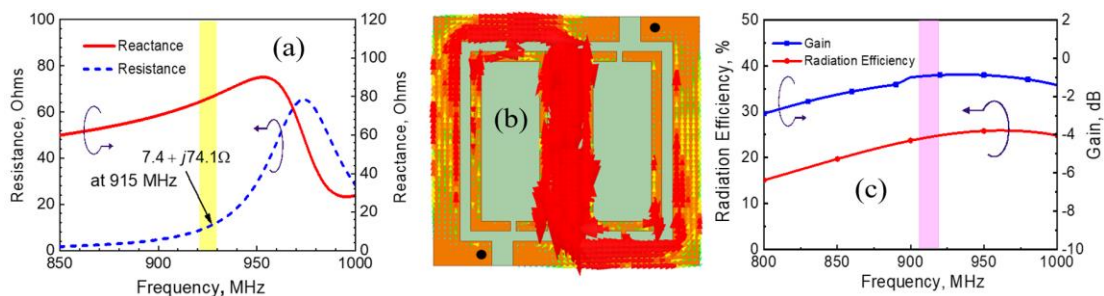


Figure 3. (a) Simulated input impedance of the proposed tag antenna compared with the conjugate impedance of the Monza 4 chip, (b) Surface current distribution at 915 MHz illustrating the excitation of the dual-loop resonant mode and the role of the shunting pin in guiding current symmetrically, (c) Simulated radiation efficiency and realized gain across 800–1000 MHz, demonstrating stable performance over the UHF RFID band

3. Results and Discussion

The antenna was tailored for seamless integration with the Monza 4 RFID chip, characterized by an input impedance of $7.4 - j74.5 \Omega$ at 915 MHz. To assess its electrical performance, impedance measurements were performed using a vector network analyzer (VNA), paired with a balun probe and a standard 50Ω coaxial cable. Prior to testing, the balun underwent meticulous calibration using open, short, and matched load standards, following the procedure outlined in [24], [25].

Figure 4a illustrates the comparison between simulated and experimental input impedance values of the antenna, alongside the reference impedance curve of the Monza 4 chip. The measured resistance and reactance closely align with simulation results throughout the UHF RFID frequency range, with slight discrepancies attributed to manufacturing variances and measurement conditions. At the target frequency of 915 MHz, the measured impedance was approximately $7.1 + j74.2 \Omega$, while simulations predicted $7.4 + j74.1 \Omega$ —both demonstrating strong conjugate matching with the chip. Additional validation was conducted through return loss and power transmission coefficient (PTC) analysis, confirming the antenna's efficiency and suitability for RFID applications [26]. Following [26], the power wave reflection coefficient (RL) is defined as follows:

$$RL = \frac{Z_{IC} - Z_{ant}^*}{Z_{IC} + Z_{ant}}, 0 \leq |RL| \leq 1 \quad (1)$$

$$RL(\text{dB}) = -20 \log |RL| \quad (2)$$

where

$Z_{IC} = R_{IC} + jX_{IC}$ is the input IC chip impedance

$Z_{ant} = R_{ant} + jX_{ant}$ is the input antenna structure impedance

The power delivered to the IC chip is expressed as follows:

$$P_{chip} = (1 - |RL|^2) P_{ant} \quad (3)$$

where P_{chip} is the power received by the antenna configuration.

To quantify the power transmission coefficient (PTC), the following relation is used:

$$PTC = \frac{P_{chip}}{P_{ant}} = (1 - |RL|^2) = \frac{4R_{ant}R_{IC}}{(R_{ant} + R_{IC})^2 + (X_{ant} + X_{IC})^2}, 0 \leq RL \leq 1 \quad (4)$$

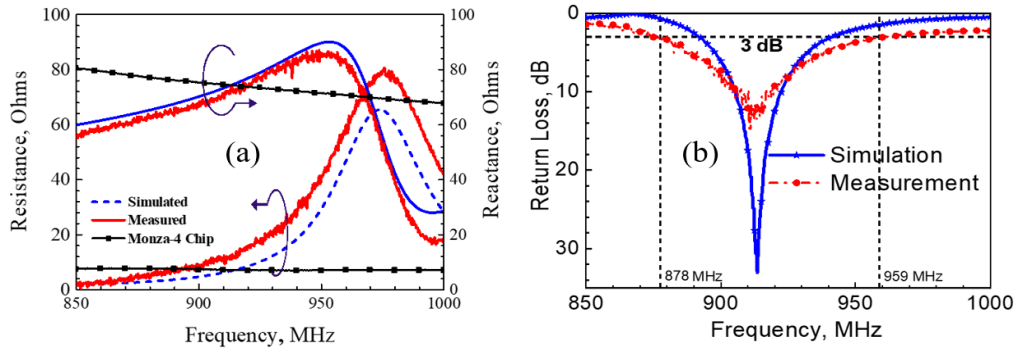


Figure 4. Experimental and simulated results for the proposed antenna with (a) input impedance and (b) return loss

The return loss characteristics of the proposed UHF RFID tag antenna are shown in Figure 4b, comparing simulated and measured results. A strong resonance is observed near 915 MHz, matching the operational band of the Monza 4 chip. The simulated return loss reaches approximately -30 dB, confirming good impedance matching between the antenna and chip.

Measured results closely follow the simulations, with slight deviations due to fabrication and measurement tolerances. The simulated 3 dB bandwidth spans 891–943 MHz (52 MHz), while the measured bandwidth extends from 878–959 MHz (81 MHz), fully covering the FCC UHF RFID band (902–928 MHz) and ensuring reliable tag performance in practical use. A key parameter for evaluating the performance of an RFID tag antenna is its read range, commonly referred to as the reading distance. The power transmission coefficient (PTC) of the proposed antenna was evaluated through both simulation and measurement, as shown in Figure 5.

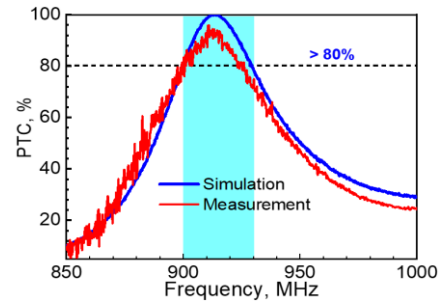


Figure 5. Comparison between measured and simulated return loss and PTC of the proposed antenna

The results demonstrate that the antenna achieves a PTC above 80% across the RFID operating band from 900 to 930 MHz, which is critical for efficient power transfer between the antenna and the Monza 4 chip. Maximum read distance is achieved when the power received by

the RFID chip (P_{tag}) equals its activation threshold (P_{active}), which defines the minimum power required to initiate the chip's operation [27]:

$$R = \frac{\lambda}{4\pi} \sqrt{\frac{P_{\text{reader}} G_{\text{reader}} G_{\text{tag}} P_{\text{TC}}}{P_{\text{active}}}} \quad (5)$$

where the parameters P_{reader} and G_{reader} correspond to the output power and directional gain of the reader antenna, respectively. G_{tag} signifies the gain of the tag antenna, while P_{active} defines the minimum power threshold necessary to activate the RFID chip and enable its operation. To evaluate the tag antenna's performance, Equation (5) was applied to calculate the expected reading distance. The prototype antenna, affixed to a metallic backing, was experimentally tested within an anechoic chamber using a measurement protocol adapted from [25], [26].

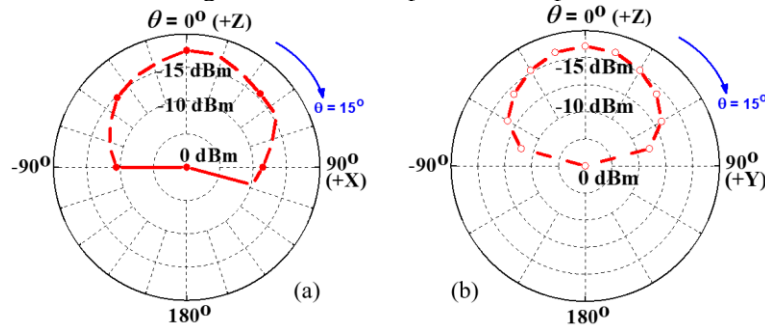


Figure 6. Angular detection characteristics of the proposed RFID tag antenna at 915 MHz across (a) XZ and (b) YZ planes

Figure 6a and 6b show the measured angular sensitivity patterns of the proposed RFID tag antenna at 915 MHz in the XZ and YZ planes. In both planes, the polar plots display angular positions of 0° , $\pm 90^\circ$, and 180° , with signal strength levels at 0, -5, -10, and -15 dBm. The red dashed curves represent the measured radiation responses, while the blue arrows at $\theta = 180^\circ$ indicate the main response direction. The nearly symmetrical patterns in both planes confirm stable and consistent radiation characteristics of the antenna.

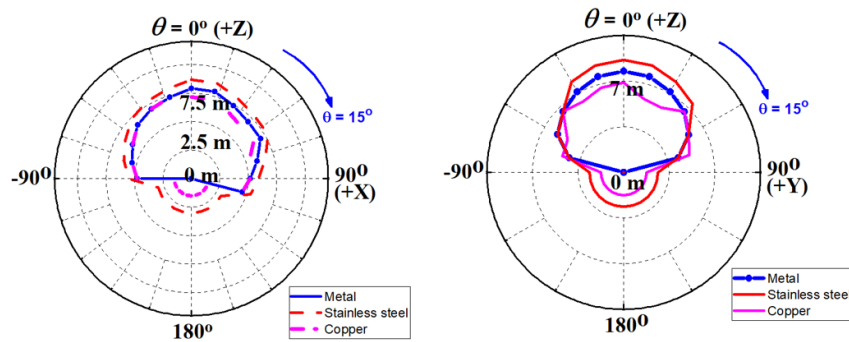


Figure 7. Experimental reading range results of the proposed RFID tag antenna on various metal plates at 915 MHz in (a) XZ and (b) YZ orientations

Figure 7a and 7b illustrate the measured directional read range of the proposed RFID tag antenna at 915 MHz in the XZ and YZ planes. In both planes, concentric circles represent distances of 0, 2.5, 5, and 7.5 m. The blue curves show the measured reading range as a function of angle, with a maximum distance of about 7.5 m near $\theta = 15^\circ$. The similar responses observed in both planes confirm the antenna's stable and symmetric radiation performance, ensuring reliable readability under different orientations. Table 3 compares the proposed tag antenna with several representative on-metal RFID designs. While existing PIFA, folded-patch, and magnetic-

loop structures generally require larger dimensions or thicker substrates to achieve comparable read ranges, the proposed dual-loop antenna attains a compact $50 \times 50 \times 0.8 \text{ mm}^3$ form factor with -2.4 dB gain, 25% efficiency, and an 81-MHz bandwidth, resulting in a stable 7.3-m read range. These results demonstrate that the proposed design offers a practical balance of compactness, simplicity, and competitive on-metal performance.

Table 3. Comparison of the proposed RFID tag antenna with existing designs and commercial tags

Ref./ Design	Antenna Type	Size (mm ³)	Substrate/ Thickness (mm)	Gain (dB)	Efficiency (%)	BW (MHz)	Read Range (m)
[9]	Slim PIFA	$70 \times 50 \times 1.6$	FR4 / 1.6	-2.5	35	58	5.0
[18]	Folded patch with inductive stubs	$60 \times 60 \times 1.0$	PET / 1.0	-1.5	40	N/A	6.8
[20]	Folded patch with orthogonal tuning slots	$65 \times 65 \times 1.6$	FR4 / 1.6	-1.2	45	N/A	7.0
[22]	Magnetic-loop on-metal tag	$55 \times 55 \times 0.8$	FR4 / 0.8	-2.0	42	N/A	7.2
[26]	3D dipole	$30 \times 30 \times 3$	FR4/(1.0 & 0.2)	-3.2	20	18	7.5
This work	Dual - loop	$50 \times 50 \times 0.8$	FR4/ 0.8	-2.4	25	81	7.3

4. Conclusions

In this paper, a compact UHF RFID tag antenna designed for metallic surfaces has been proposed, analyzed, and experimentally validated. The antenna was realized on a low-cost FR4 substrate and optimized for integration with the Monza 4 chip, which has an input impedance of $7.4 - j74.5 \Omega$ at 915 MHz. To achieve conjugate impedance matching, a dual-loop radiating structure with a tunable shorting mechanism was employed. The final design successfully provided stable matching at 915 MHz, achieving a measured impedance of approximately $7.4 + j74.1 \Omega$, which is in excellent agreement with simulation results. Performance evaluation confirmed that the antenna exhibits favorable characteristics, including a wide measured bandwidth of 878–959 MHz fully covering the FCC UHF RFID band, a power transmission coefficient (PTC) exceeding 80% across 900–930 MHz, a maximum read range greater than 7.3 m under 4 W (EIRP), and acceptable radiation efficiency and gain despite its compact, low-profile configuration.

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