Low-Cost Circularly Polarized Conical Beam RFID Antenna for Indoor Access Point Integration

Melissa Zebboudj[1,2], Francis Keshmiri[1]
[1] Huawei Technologies, Boulogne-Billancourt, France, zebboudj.melissa@huawei.com
[2] EURECOM, Sophia Antipolis, France

***Abstract*— This paper presents a low-cost circularly polarized conical-beam RFID antenna designed for integration with indoor access points. The antenna consists of two FR-4 PCB layers, where the lower layer represents the access point PCB and serves as the ground plane and mechanical support of the RFID antenna, while the upper layer contains horizontal radiating elements that excite the TM_{02} mode to generate the conical radiation pattern. Radial meandered feed lines provide in-phase excitation to perimeter radiating arcs, enabling a compact structure. Four central screws connecting two PCBs also act as conductive RF pins, carrying vertical current flows. The resulting circular polarization achieves an axial ratio below 3 dB across the entire 920 – 925 MHz RFID band. The simulated results demonstrate a realized gain above 1 dBi and a radiation efficiency of approximately 75%, making it suitable for cost-effective indoor RFID applications.**

***Index Terms—RFID*, FTTR, conical-beam, propagation, circular polarization, Indoor Access Point.**

I. Introduction

With the development of fiber-optic indoor networks, Fiber-To-The-Room (FTTR) solutions enable high-speed and reliable Wi-Fi coverage in every room of a residence. An FTTR system typically consists of a main unit, referred to Master FTTR Unit (MFU), and multiple secondary units, knowns as Sub FTTR Units (SFUs), forming a centralized Point-to-Multipoint (P2MP) topology [1-2]. This architecture ensures reliable service delivery and enables unified network management across all SFUs.

Antennas play a crucial role in FTTR systems by providing flexible coverage and stable connectivity, through fixed-beam antennas with either directive or omnidirectional radiation patterns [3], as well as reconfigurable antennas capable of intelligently distributing beams among multiple access points and users [4]. FTTR antennas can adapt to diverse use cases in both residential [5] and professional environments such as industrial or office environments [6-7]. Furthermore, compact multi-band filtering antennas integrated in MFU and SFUs [8] can enable Wi-Fi communications supporting Multi-Link Operations (MLO), as key Wi-Fi 7 feature defined in *IEEE 802.11.bn*.

Although indoor localization using Wi-Fi signals has been widely studied as the Integrated Sensing and Communication (ISAC), relying solely on communication waveforms often limits positioning accuracy in complex and dynamic indoor environments due to multipath propagation, polarization mismatch, and environment variations. Employing a dedicated RFID technology and frequency band specifically optimized for indoor localization can provide higher precision and robustness, while complementing the communication function of FTTR Wi-Fi access points [9], enabling advanced features such as adaptive coverage optimization and AI-enabled intelligent connectivity. Therefore, integrating RFID capability directly into FTTR access points requires compact and compatible antenna solutions that can operate in parallel with existing Wi-Fi antennas. By embedding dedicated RFID antennas within the access point hardware and leveraging Wi-Fi links primarily for coordination between MFU and SFUs, accurate global localization can be achieved even when access point placements are not optimal.

In RFID systems, circularly polarized antennas with conical radiation patterns (for ceiling-mount devices) offer key advantages, including reduced sensitivity to tag orientation, wider and more uniform indoor coverage, improved reliability, and enhanced robustness in multi-path environments, making them well suited for indoor tracking with randomly distributed tags and users. Conical beams are commonly realized by exciting higher-order modes such as TM_{02}, TM_{01} [10-11], or TM_{21} [12], while circular polarization is achieved through multiport feed networks with phase shifts or structural modifications of the radiator and its current distributions [10], [12]. However, these approaches often increase design complexity, fabrication sensitivity, and fabrication costs.

To address these challenges, this work proposes a circularly polarized conical-beam RFID antenna designed for indoor localization, and integration into ceiling-mount FTTR access points. The proposed architecture eliminates complex feeding networks and external phase-shifting components, simplifying implementation while keeping stable circular polarization and uniform conical coverage, with its novelty supported by a patent [13].

II. Antenna Architechture and Operation

Fig. 1 demonstrate the proposed antenna which consists of two FR4 PCB layers, both with a relative permittivity of $\varepsilon_r = 4.4$ and a thickness of h = 1.2 mm, which is a commonly used material for less-expensive manufacturing. The bottom PCB has a square shape with a side length of L = 240 mm, which can also function as the main PCB of the possible host product, while the upper PCB has a circular shape with a diameter of D = 200 mm and includes the horizontal radiating elements. The distance between the two layers is H = 15 mm.

The antenna is fed at the center using four *M6* vertical screws that carry the RF signal to the upper radiating layer. Several vias are placed at the PCB connection points to ensure stable electrical contacts. The screws also provide mechanical support for the upper PCB, while few plastic spacers between the two layers can be added to improve assembly accuracy and placement tolerances. The upper radiating layer operates in the TM_{02} mode, which generates a conical beam radiation pattern.

Fig. 2 illustrates the operating mechanism of the proposed antenna. The distribution of surface currents on the top layer is shown in Fig. 2(a), which demonstrates that the currents flowing along the meandering lines do not radiate constructively and do not contribute significantly to the radiation. Instead, these lines primarily transport the RF signal from the center to the radiating arcs of the curved monopole and feed them in phase. Fig. 2(b) shows the electric field distribution calculated at a distance of 3 cm above the antenna, where the meandering lines modify the TM_{02} mode, reshaping the field and producing minimal radiation from the central region of the antenna. In contrast to the conventional TM_{02} mode, which exhibits a purely radial electric field distribution, the radiating arcs introduce an additional azimuthal component, thereby perturbing the original mode.

The circular polarization of the antenna is achieved by the combination of V-pol fields radiated from the vertical feeder and H-pol fields radiated from the arcs located near the edge of the upper layer. The 90° phase difference between these two orthogonal components is controlled by the length of the non-radiating meander lines. This design ensures that the two components combine coherently at an observation distance of approximately one wavelength (λ), resulting in circular polarization with a good axial ratio.

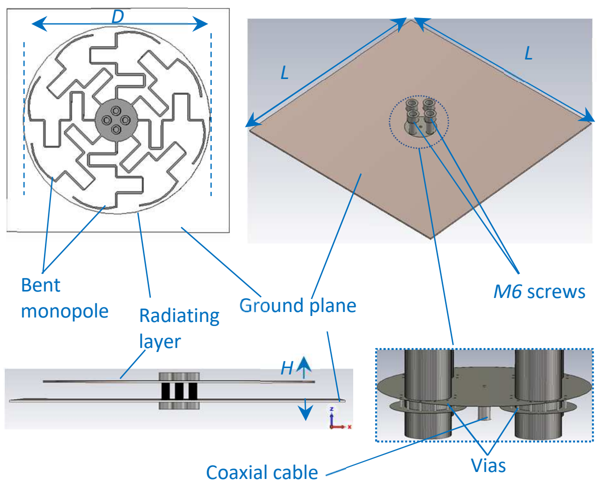

Fig. 1 Architecture of proposed RFID antenna with two FR4 PCB layers, and the central feeder.

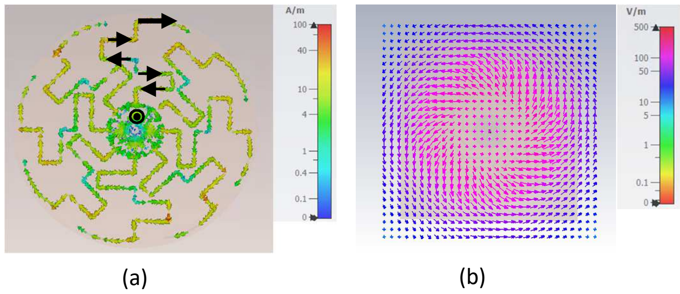

Fig. 2 Surface current and electric field distributions of the proposed antenna: surface current distribution with simplified black arrows indicating vertical and horizontal current flows (a), and electric field distribution illustrating the modified TM_{02} mode (b).

III. Simulated Performance

The simulation results of the proposed RFID antenna, using *CST Microwave Studio*, are presented in this section. Fig. 3 shows the simulated return loss (in dB) and the axial ratio (*AR*) versus frequency. The return loss remains below –15 dB, indicating good impedance matching over the full RFID band (i.e., 920 MHz to 925 MHz). Within the same band, the AR remains below 3 dB, confirming effective circular polarization.

Fig. 4 shows the radiation patterns of the antenna in the E-plane, demonstrating conical shapes due to the TM_{02} mode at both the beginning and the end of the RFID band. It also shows 3D radiation patterns of the realized gain, with maximum gain slightly above 1 dBi over RFID band.

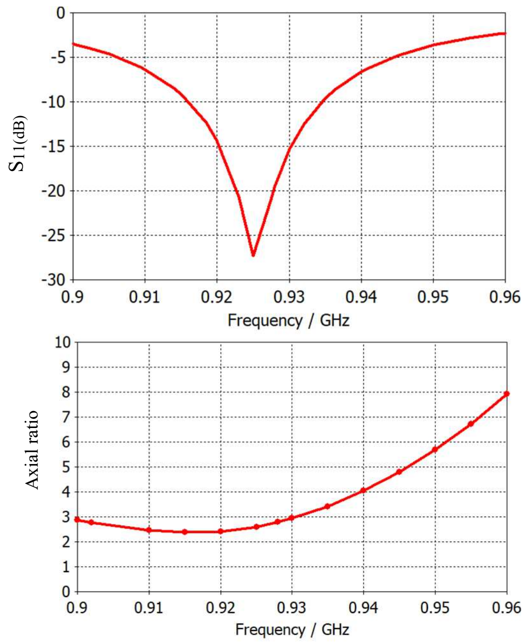

Fig. 3 Return loss versus frequency in dB (top), and axial ratio in linear (bottom) of the proposed antenna as shown in Fig. 1.

Fig. 5 shows the total radiation efficiency of the proposed antenna versus frequency, achieving approximately 75% efficiency across the entire RFID band, which indicates acceptable performance for indoor RFID access point applications. The dielectric losses, as well as fabrication and assembly tolerances, should be carefully considered if a high radiation efficiency is required. In particular, for ceiling-mounted access point applications (for example in FTTB applications [4-7]), where mainly forward radiation (along z-axis) is desired, a larger ground plane should be additionally considered to improve the front-to-back ratio.

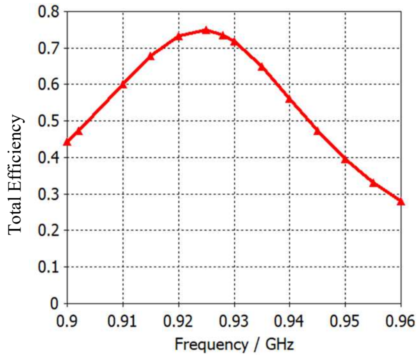

Fig. 5 The total radiation efficiency (linear) of the proposed antenna, versus frequency.

IV. Conclusion

A low-cost circularly polarized conical-beam RFID antenna has been proposed and analyzed for indoor access point applications in the 920 – 925 MHz band. The simulated results demonstrate good impedance matching, stable circular polarization with an axial ratio below 3 dB, and a conical radiation pattern providing uniform spatial coverage for FTTR applications. The antenna achieves a realized gain of approximately 1 dBi and a radiation efficiency of about 75% across the operating band, confirming its suitability for short-range indoor RFID deployments.

The proposed design offers a simple structure with reduced fabrication complexity, making it an attractive candidate for cost-sensitive applications. A prototype of the antenna is currently under fabrication, and future work will focus on experimental validation of the simulated results and evaluation of its performance in practical deployment scenarios, including ceiling-mounted access point configurations.

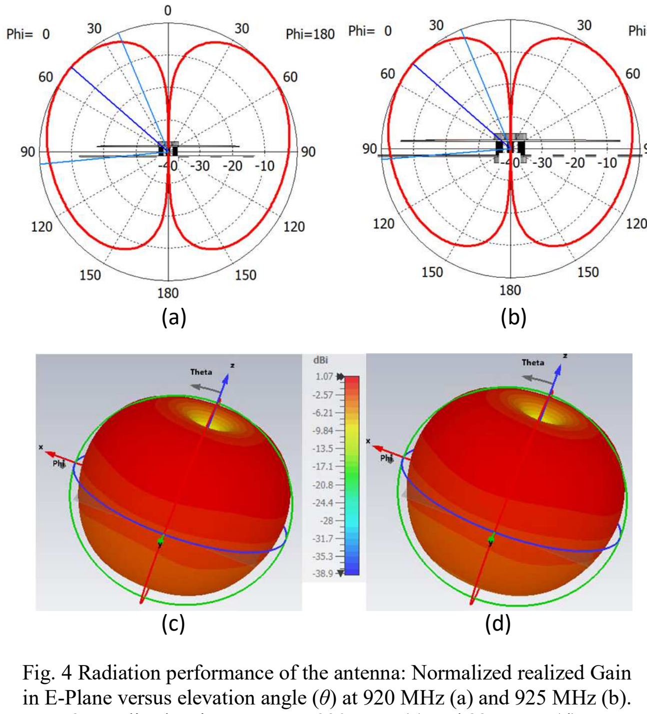

Fig. 4 Radiation performance of the antenna: Normalized realized Gain in E-Plane versus elevation angle (θ) at 920 MHz (a) and 925 MHz (b). 3D realized Gain patterns at 920 MHz (c) and 925 MHz (d).

References

[1] GSTP-FTTR Use cases and requirements of FTTR, ITU-T, Apr. 2021

[2] ETSI GR F5G 002, F5G Use Cases standard, Release #3, Jun. 2024

[3] Y. Dong, J. You and F. Keshmiri, "Review on the New Antenna Evolution for Next Generation WiFi-7/8 Systems," 2025 19th European Conference on Antennas and Propagation (EuCAP), Stockholm, Sweden, 2025.

[4] C. D. Giovampaola, F. Keshmiri, F. Caminita, Y. Zeng and S. Maci, "Low-Profile Wi-Fi Antenna with Reconfigurable Metasurface for FTTR Applications," 2025 19th European Conference on Antennas and Propagation (EuCAP), Stockholm, Sweden, 2025

[5] F. Keshmiri, H. Xiong, Z. Ren, "Smart antenna for optical network terminals and indoor optical network" WO Patent 2024007210A1, 2024

[6] C. Chen, X. Xu, L. Zhang and F. Keshmiri, "Compact Horizontally Polarized Dual-Beam Antenna with Large Tilted Beam Angle for FTTR Applications," 2025 19th European Conference on Antennas and Propagation (EuCAP), Stockholm, Sweden, 2025

[7] D. Li *et al.*, "A Low-Cost High-Gain Dual-Beam Antenna With Large Beam Tilt Angle for Through-Wall FTTR Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 24, no. 12, pp. 4750-4754, Dec. 2025

[8] Y. Dahmani and F. Keshmiri, "C-Slotted Patch Filter Antenna with Triple Notches for Enhanced Wi-Fi Performance," 2025 19th European Conference on Antennas and Propagation (EuCAP), Stockholm, Sweden, 2025.

[9] S. Zhang, J. Li, J. Zhu, D. Zhang, Y. Zeng and Y. Luo, "First Demonstration of FTTR-based RFID Network for Integrated Sensing and Communication," 2025 Asia Communications and Photonics Conference (ACP), Jiangsu, China, 2025.

[10] W. Yang, C. Huang, X. Zhu, W. Huang and L. Xu, "A Wideband Circularly Polarized Antenna With High Impulse Signal Fidelity for IR-UWB Positioning Applications," in IEEE Transactions on Circuits and Systems, vol. 71, no. 4, pp. 1944-1948, April 2024.

[11] S. Wang, L. Zhu, G. Zhang, J. Yang, J. Wang and W. Wu, "Dual-Band Dual-CP All-Metal Antenna With Large Signal Coverage and High Isolation Over Two Bands for Vehicular Communications," in IEEE Transactions on Vehicular Technology, vol. 69, no. 1, pp. 1131-1135, Jan. 2020.

[12] W. Lin, H. Wong and R. W. Ziolkowski, "Circularly Polarized Antenna With Reconfigurable Broadside and Conical Beams Facilitated by a Mode Switchable Feed Network," in IEEE Transactions on Antennas and Propagation, vol. 66, no. 2, pp. 996-1001, Feb. 2018.

[13] F. Keshmiri, M. Zebboudj, H. Xiong, "RFID antenna with circular polarization and conical beam for indoor WLAN access point integration, PCT118385 Patent filled September 2025.