Circular Polarized RFID Tag Antenna Design using Characteristic Mode Analysis

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***Abstract*—This paper presents a circularly polarised RFID tag antenna using characteristic mode analysis. The proposed design consists of a leaf-shaped radiator with two cross slots and shorting stubs etched on a grounded FR4 substrate. By analyzing the characteristic modes, the diagonal slots are created at suitable locations to enable modes to resonate in the required frequency band. In addition to this, edge rounding is perfumed to create modes with orthogonal current distribution for circular polarisation. Moreover, the RFID chip is placed as a capacitive coupling element at current minima to excite these orthogonal modes. Furthermore, the tag parameters are optimized to give a conjugate match with Alien H4 RFID chip in US UHF RFID band (902 – 928 MHz). The proposed tag provides a read range of 3.5 m and 5 m after mounting on low permittivity substrate and 100 x 100 mm^2 metallic plate, respectively.**

Keywords—circular polarised, characteristic mode analysis, RFID tag, impedance match,

I. Introduction

Radio-frequency Identification (RFID) and the Internet of things have emerged in numerous applications such as inventory management, electronic toll collection tracking, monitoring, etc. The passive UHF RFID technology is the most promising due to its low-cost and easy to printable tag structures. However, the UHF tags are very sensitive towards tagging surfaces such as metals, water, and other high permittivity materials. The performance of UHF tag seriously deteriorates near the vicinity of metals due to different boundary conditions. Moreover, most of the commercial UHF tags consist of T-match structure, embed with a dipole are linearly polarised. So, these conventional tags are orientation sensitive and cannot be readable in all orientations. Also, it is common to use circularly polarised reader antenna to avoid orientation problem of linearly polarised tag at the expensive of 3dB loss due to polarisation mismatch, which reduces read range of RFID tags [1-5].

Consequently, a circularly polarised RFID tag antenna is suitable to solve orientation issues without additional loss due to polarisation mismatch. There are several circularly polarised UHF RFID tags have been reported in the literature. However, most of the tag designs consist of PIFA with vias, which make these designs expensive and further their performance highly depends on the location of vias [6-8]. Furthermore, the microstrip circular polarised tag proposed in [9-10] and [11-13] have no via or shorting pins; however, they have large dimensions.

Therefore, in this paper, a compact circularly polarised RFID tag antenna using characteristic mode analysis is presented. By analyzing different characteristic modes (CMs) of proposed tag, two CMs with orthogonal current distribution are exploited to achieve circular polarisation. Firstly, the diagonal slots are created at suitable locations to enable modes to resonate in the required frequency band. Secondly, the edge rounding is perfumed to create modes with orthogonal current distribution for circular polarisation. Moreover, the RFID chip is placed as a capacitive coupling element at current minima to excite two CMs with orthogonal current distribution to achieve circular polarisation. The proposed tag poses a low-cost solution due to the absence of via or shorting pins. Also, it has small dimensions 40 x 40 x 2 mm^2 with a read range of 3.5 m and 5 m after mounting on low permittivity substrate and 100 x 100 mm^2 metallic plate, respectively.

II. Antenna Design

Fig. 1 shows the geometry and detailed dimensions of the proposed tag antenna. The tag design consists of a leaf-shaped radiator with cross slots etched on a grounded FR4 substrate. Additionally, one shorting stub is connected with ground plate near to one end of RFID chip, while the other shorting stub was connected to ground plate diagonally opposite end of the leaf-shaped radiator. Alien Higgs H3 was employed as an RFID chip with impedance 27-201j at 915 MHz. The fabricated prototype of an RFID tag is shown in Fig. 2.

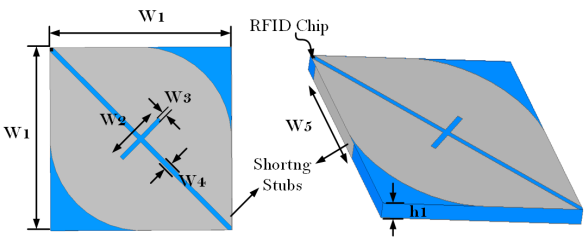

Fig. 1. Geometry of proposed RFID tag antenna (W_1=40, W_2=16, W_3=0.5, W_4=0.5, W_5=12, h_1=2)

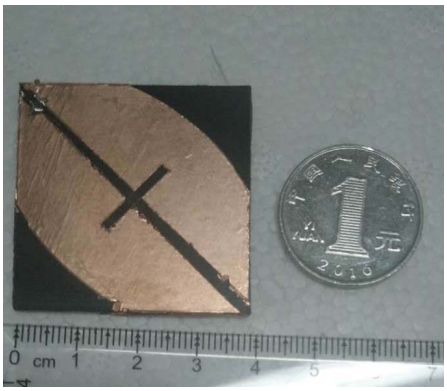

Fig. 2. Fabricated prototype of the proposed RFID tag

III. CMA OF PROPOSED RFID TAG

Starting with 40 x 40 mm2 radiating plate mounted on grounded FR 4 substrate, we observed some modes are resonating near 2 and 3 GHz. The long diagonal slot was created to scale down the frequency of resonating modes in the required US RFID band. Moreover, in order to achieve circular polarisation, a small diagonal slot, and the edge truncation and was performed. Fig. 3 shows the modal significance of the first six modes of proposed tag antenna. The modal significance shows the mode 1 and 2 are more significant modes with good radiation capability and are resonating at 940 MHz and 870 MHz, respectively. Mode 3, 4, 5 and 6 have modal significance value less than 0.2, which shows their less radiation capability in UHF RFID band. In addition to this, characteristic angle also shows the exact resonating frequency of CMs. Since the information of characteristic angle is required for circular polarisation, therefore Fig. 4 shows the characteristic angle of first six modes of proposed tag antenna. The mode 1 and 2 have a difference of 90^0 between characteristics angle at 920 MHz, which is vital for circular polarisation. As other modes (3, 4, 5 and 6) have characteristics angle between 90^0 to 180 ^{0}, so posing an inductive behavior [13-16]. Fig. 5 shows the current distribution of the first six modes of proposed RFID tag antenna.

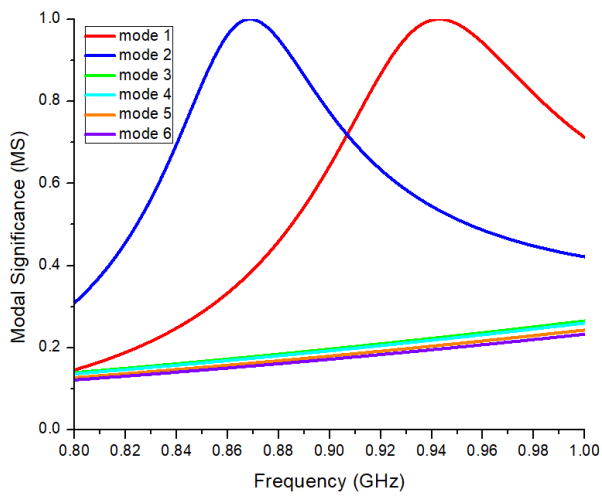

Fig. 3. Modal significance of the first six modes of proposed tag antenna.

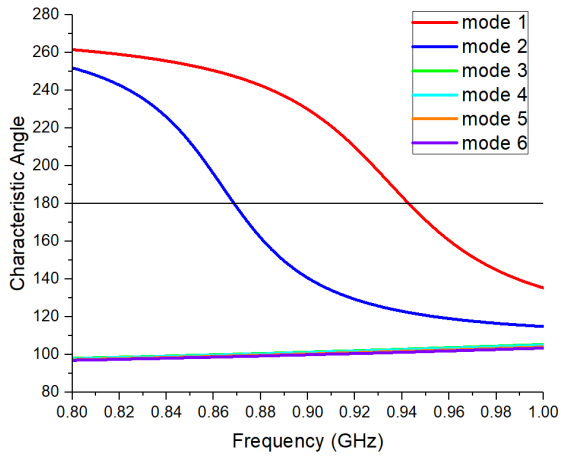

Fig. 4. Characteristic angle of first six modes of proposed tag antenna.

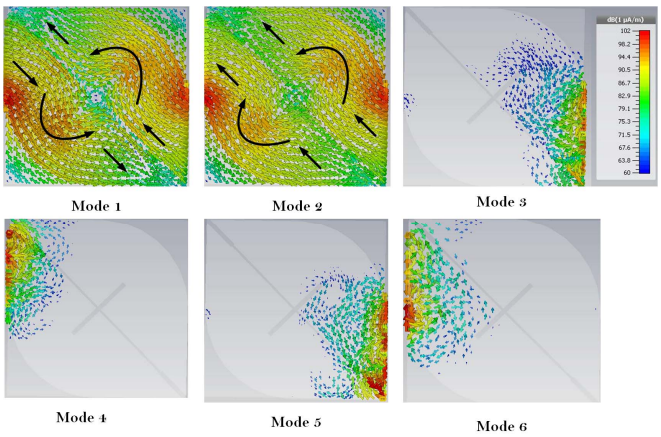

Fig. 5. Current distribution of the first six modes of proposed RFID tag antenna.

The current distribution also validates the significance and radiation capability of mode 1 and 2. Furthermore, the current distribution provides information about the feed position to excite both modes simultaneously with orthogonal current distribution to achieve circular polarisation. The current distribution of other modes does not illustrate any pattern except inductive behavior. It is clear from Fig. 5; the RFID chip can be placed as a capacitive coupling element at current minima of both modes (which is located at the upper and lower corner of the long diagonal slot) to excite modes 1 and 2 simultaneously.

IV. CMA OF PROPOSED RFID TAG

After performing CMA, the parameters of the proposed tag are further optimized using CST microwave studio to achieve impedance match with Alien Higgs H3 RFID chip. The impedance of the proposed tag is shown in Fig. 6. The real impedance of tag antenna varies from 20 ohms to 30 Ohms in US RFID band. Additionally, the value of real impedance is drastically increased after this frequency band of interest. However, the imaginary impedance is also ranging from 190 to 220 Ohms, which provides good impedance, match with RFID chip. Additionally, the return loss and axial ratio of this tag design are shown in Fig 7. The 3dB bandwidth of this tag design is ranging from 890 to 935 MHz, with an axial ratio less than 3 dB 900 MHz to 925 MHz, which shows the potential of this compact, low-cost tag design towards circular polarization.

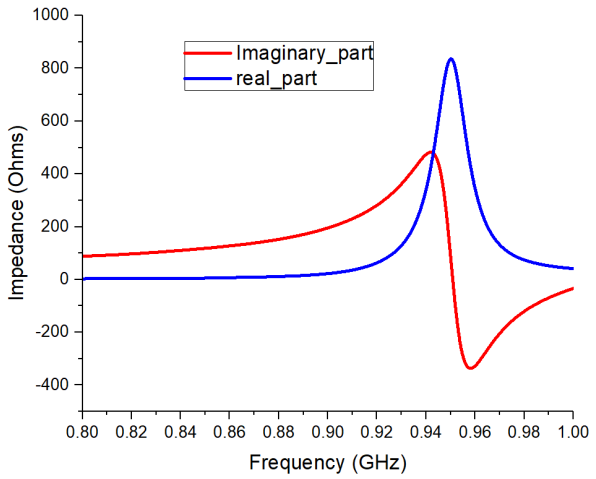

Fig. 6. Impedance of the proposed RFID tag design

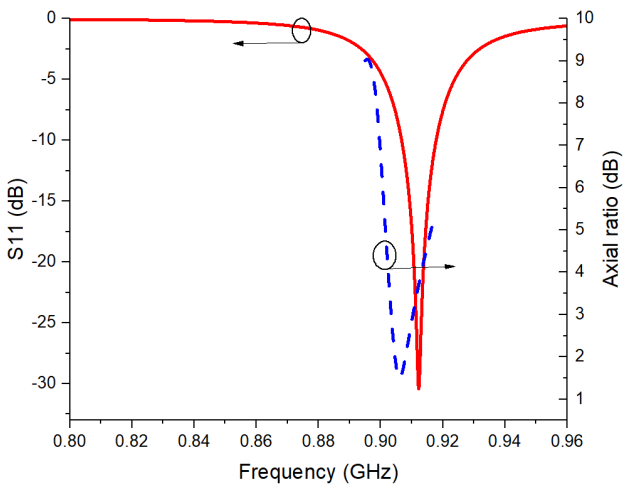

Fig. 7. Return loss and axial ratio of the proposed tag design

V. Conclusion

This paper proposes a compact circular polarised RFID tag antenna using characteristic mode analysis. By analyzing different modes of proposed tag antenna, the diagonal slots were created at suitable locations to enable modes to resonate in the required frequency band.

Moreover, the edge rounding was performed to create modes with orthogonal current distribution for circular polarisation. The RFID chip was placed as a capacitive coupling element at current minima to excite these orthogonal modes. Furthermore, the tag parameters are optimized to give a conjugate match with Alien H4 RFID chip in US UHF RFID band (902 – 928 MHz). The proposed tag provides a read range of 3.5 m and 5 m after mounting on low permittivity substrate and 100 x 100 mm^2 metallic plate, respectively.

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