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Circularly Polarized Meander Line Cross Dipole Antenna for UHF RFID Applications

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1. Abstract

In this paper, a new cross dipole Radio Frequency Identification circularly polarized tag antenna operating in the ultra-high frequency region is introduced. Circular polarization is achieved using two unequal orthogonal dipoles. The arms of the orthogonal dipoles are meandered and loaded with capacitive tips for size miniaturization. A meandered T-match network is used to obtain impedance matching with Impinj Monza-4 tag chip used for the design. The measured 10-dB return loss bandwidth and the 3 dB axial ratio bandwidth are 17 MHz (908-923 MHz) and 6 MHz (912-918 MHz) respectively. A significant improvement in the read range of the proposed antenna compared to a linearly polarized antenna of similar gain and reflection coefficient, from 10.9 m to 15.66 m, has been achieved due to reduced polarization mismatch between the tag and the reader antennas.

2. Introduction

Radio Frequency Identification (RFID) has emerged as one of the key players in the automatic identification industry making its presence across different sectors including supply chain management, product tracking, security systems, health care and logistics [1]. Different parts of the frequency spectrum are used for RFID applications, viz. low frequency (LF, 125-134 KHz), high frequency (HF, 13.56 MHz), ultra-high frequency (UHF, 860-960 MHz) and microwave frequency (2.45, 5.8 and 24 GHz) bands [2]. For different applications, it is essential to design tag antennas with higher reading distances. Apart from providing greater storage capacity and faster reading speeds, UHF RFID systems offer longer read ranges compared to LF and HF systems [3]. One of the methods to improve read range is to decrease the polarization mismatch between the tag and the reader antennas [4]. In general, the commercially available reader antennas are circularly polarized (CP). Linearly polarized (LP) tag antennas can receive only half of the transmitted power from a CP reader antenna owing to polarization mismatch. However, circularly polarized tag antennas can receive 3 dB more transmitted power from CP reader antennas, which in turn leads to 41% enhancement in the read range [5].

In this paper, a circularly polarized UHF RFID tag antenna has been proposed. The antenna operates at 915 MHz and employs two unequal orthogonal dipoles to achieve circular polarization. The cross dipoles are meandered to reduce the overall dimension of the antenna. Furthermore, a modified T-match network is introduced for impedance matching with Impinj Monza 4 tag chip, which has an impedance of 11-j143 Ω at 915 MHz.

3. Antenna Design

The circularly polarized meander line cross dipole antenna is designed on a 58×58 mm^2 FR-4 substrate with permittivity, ε_r=4.4, loss tangent, tan δ=0.02, and thickness 1.6 mm. The geometry of the proposed tag antenna is presented in Figure 1 (a). The antenna consists of two linearly tapered orthogonal dipoles. To achieve circular polarization, the cross dipoles must have excitations of equal magnitudes but opposite in phase. The horizontal and vertical dipoles are unequal in length. The vertical dipole is connected with two semi-circular curves and is slightly longer than the horizontal dipole. This inequality in length helps to attain the required phase relationship for circular polarization. Moreover, to reduce the coupling effect between the two dipoles, the vertical dipole is strategically located at the neutral potential plane of the horizontal dipole. The input impedance of the horizontal and vertical dipoles are 22.05+j136.8 Ω and 12.03+j149.41 Ω at 915 MHz respectively. The reflection coefficients of the dipoles have been calculated individually using the formula,

$$\Gamma = \frac{Z_a - Z_c^*}{Z_a + Z_c} \quad (1)$$

Where, Z_a refers to the impedance of the dipoles and Z_c is the input impedance of the chip. It has been found that the phase difference between the two dipoles is 84^0, which fairly satisfies the phase difference requirement of the cross dipoles to yield circular polarization.

The arms of the dipoles are meandered with capacitive tip loadings for size miniaturization. However, too many meanders tend to degrade the radiation efficiency as currents flowing in the adjacent arms of the meander are out of phase and cancel each other [6]. To avoid this impact on the efficiency of the antenna, non-uniform meanders have been considered instead of uniform meanders. The two dipoles are simultaneously excited by the same impedance matching network. To allow for maximum power transfer between the tag antenna and the tag IC, the antenna employs a meandered T-match network to have conjugate impedance matching with the chip.

The simulation of the proposed design has been performed on Finite Element Method based HFSS EM solver. The optimized parameters of the proposed antenna are L=58 mm, L_1=47.2 mm, L_2=4.4 mm, L_3=12.6 mm, L_4=3.8 mm, L_5=11.5 mm, W_1=3 mm, W_2=0.8 mm, W_3=1 mm, g=0.9 mm, g_1=0.4 mm, h=3.2 mm.

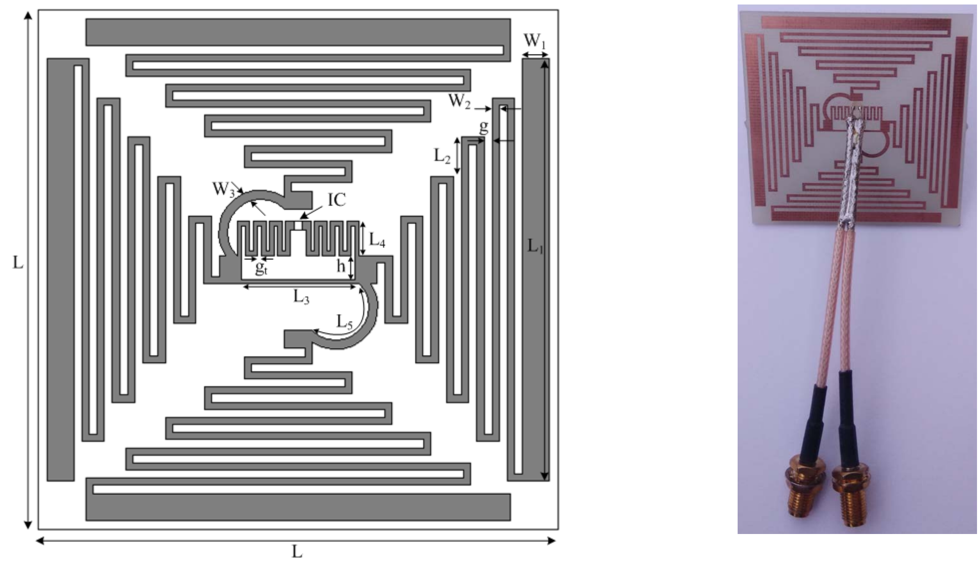

Figure 1. (a) Geometry of meander line cross dipole circularly polarized antenna with capacitive tip loading (b) Fabricated prototype with differential probe.

4. Results and Discussion

The antenna is fabricated by etching out copper from a copper-plated FR-4 substrate. Measuring instruments terminated with un-balanced ports are incapable of characterizing the balanced antennas directly. Therefore, differential probes are employed to measure the S-parameters of the proposed antenna using Anritsu Vector Network Analyzer. The fabricated prototype of the antenna with differential probes is depicted in Figure 1 (b). The antenna impedance is then calculated from the S-parameters using the conversion formula [7] and is shown in Figure 2.

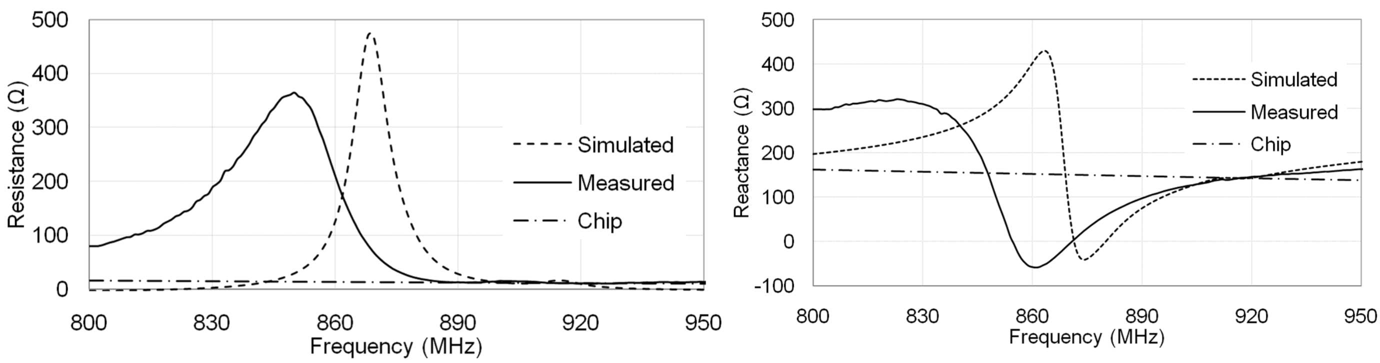

Figure 2. The simulated and measured input (a) resistance and (b) reactance of the proposed antenna.

At 915 MHz, the measured and simulated input impedances of the antenna are found to be 11.12+j140.65 Ω and 16.34+j142.25 Ω respectively. Figure 3 illustrates the measured and simulated reflection coefficients of the antenna. The measured 10-dB return loss bandwidth is 17 MHz (908-923 MHz). The axial ratio of the antenna is plotted in Figure 4 and a 3 dB axial ratio bandwidth of 6 MHz (912-918 MHz) has been recorded.

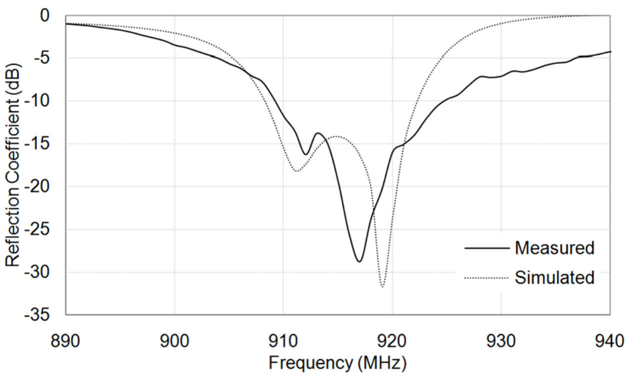

Figure 3. Measured and simulated reflection coefficients of the proposed antenna.

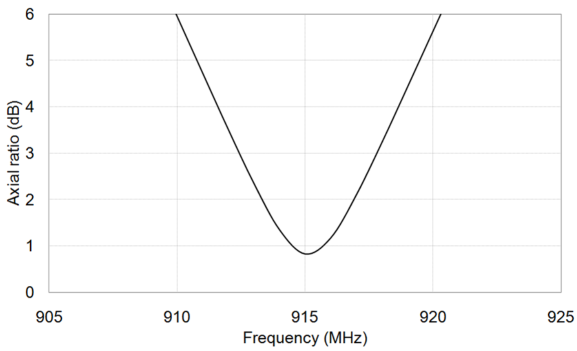

Figure 4. Axial Ratio of the proposed antenna.

The read range (r) of the antenna is calculated using Friis' free space formula [5]:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r (1-|\Gamma|^2)\rho}{P_{th}}} \qquad (2)$$

Where, P_t is the power transmitted by the reader antenna. G_t and G_r are the gain of the tag and the reader antenna respectively. P_{th} is the threshold power of the chip which is -17.4 dBm in case of Impinj Monza-4 IC. ρ is the polarization efficiency whose value is equal to 0.5 for LP tag antennas and 1 for CP tag antennas when reader antenna is circularly polarized. τ is the power transmission coefficient denoted by,

$$\tau = \frac{4\, R_c R_a}{|Z_a + Z_c|^2} \qquad (3)$$

Using (2) and (3), the read range of the proposed CP tag antenna is calculated to be 15.66 m at 915 MHz. For a linearly polarized antenna of comparable gain and reflection coefficient, the read range would have been 10.9 m. Thus, a significant improvement in the reading distance has been noted. Figure 5 shows the measured and simulated maximum read range of the proposed CP tag antenna.

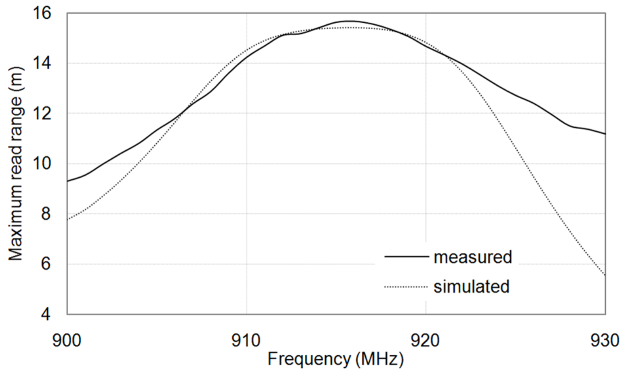

Figure 5. Simulated and measured read range of the protoype.

5. Conclusion

A circularly polarized meander line cross dipole RFID tag antenna operating at 915 MHz has been presented. The antenna attains circular polarization with the linearly tapered orthogonal dipoles. The arms of the orthogonal dipoles are meandered and loaded with capacitive tips for compactness. Impedance matching between the antenna and the tag chip has been achieved using a meandered T-match structure. The proposed tag antenna exhibits a 10 dB return loss bandwidth of 17 MHz from 908 MHz to 923 MHz and a corresponding axial ratio bandwidth of 6 MHz (912-918 MHz). When compared to a linearly polarized RFID tag antenna of equivalent gain and return loss, the proposed antenna has better polarization match with the circularly polarized reader antenna resulting in an improved read range of 15.66 mm.

6. References

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