DESIGNS OF READER AND TAG ANTENNAS FOR RFID APPLICATIONS IN UHF BAND

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1. Introduction

Recently, radio frequency identification (RFID) is gaining popularity in many applications because they have a broad detectable range, the ability to read multiple objects, fast reading speed and good security. RFID systems consist of a reader and a tag, and the antennas for the reader and the tag are principally affect overall system performance since they exchange identification information using electromagnetic wave radiation. In order to meet a required readable range with restricted system power, antennas for RFID applications should have high efficiency, low return loss and good antenna gain. A high quality of circular polarization (CP) in a wide range of frequency is especially important for reader antennas, where the proper radiation pattern is needed to broaden the readable range of the system [1]. For tag antennas, a small and planar profile is strongly desired to allow for easy attachment to an object. Additionally, the antenna must have stable radiation performance nearby various dielectric materials, and the readable range of the tag should not change much with changes in rotation angle.

This paper proposes new designs for RFID antennas that operate at the UHF band. Antennas were designed considering the aforementioned RFID antenna characteristics. We propose a novel reader antenna called the multi-layered polygonal helix antenna (MPHA), which consists of wire wound around multi-layered polygons. We also propose a new tag antenna consisting of a dipole and a loop structures. The tag antenna is designed to achieve an omni-directional readable range that allows the tag to be stably detected irrespective of its rotation angle. Detailed design parameters of both antennas are determined using a Pareto genetic algorithm in conjunction with full wave EM simulation code such as Numerical Electromagnetic Code (NEC) and IE3D. Optimized results were verified by fabricating samples of the optimized antennas on low cost substrate materials and comparing measured results to simulated results.

2. Antenna geometry and optimization

The proposed MPHA with two layered polygons working at 912 MHz is shown in Fig. 1(a), (b) and (c). As shown in Fig. 1(a) and (b), the microstrip line on the MPHA is first wound outside the polygonal shaped layer and is then wound on the inner layer. Each layer is bent with the inner angles of ϕ_{poly}, as shown in Fig. 1(b), and the microstrip lines on each layer are printed with the pitch angles of θ_{pitch}, as shown in Fig. 1(c). The parameters of ϕ_{poly} and the number of layers mainly account for the overall gain and radiation pattern of the MPHA. The parameters of ϕ_{poly} with θ_{pitch} determine the distribution of the induced current of the microstrip lines on each layer, which allows for CP radiation control and low return loss. More specifically, θ_{pitch} can have either negative or positive values for easy control of the phase of the current on the microstrip line, which allows the broadband CP characteristic to be achieved. For the tag antenna, we studied various antenna structures to remove the nulls in radiation on arbitrary angles so as to achieve an omni-directional readable range irrespective of tag rotation. We determined that the omni-directionality characteristic could be achieved by simultaneously using a folded dipole and a loop. The proposed antenna consists of this structure and is shown in Fig. 1(d).

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Table 1. Normalized cost functions for Pareto GA optimization.

Cost functions for the reader antenna	Cost functions for the tag antenna
1. $Cost1 = \frac{1}{2}\left(1 - \frac{Eff_{Reader} \times BW_{Reader}}{BW_{RFID}}\right) + RQ$ 2. $Cost2 = \frac{1}{2}\left(1 - \frac{CPBW_{Reader}}{BW_{RFID}}\right) + AQ$ 3. $Cost3 = Size_{Norm}$ 4. $Cost4 = 1 - \frac{RR_{Reader}}{RR_{RFID}}$	1. $Cost1 = 1 - \frac{Eff_{Tag} \times BW_{Tag}}{BW_{Theory}}$ 2. $Cost2 = \frac{\left\|\Gamma_{w/o\ material} - \Gamma_{with\ material}\right\|}{\Gamma_{w/o\ material}}$ 3. $Cost3 = \frac{G_{\max} - G_{\min}}{G_{dev,ref}}$
Design goals	Design goals
1. Broad matching BW and high Eff. 2. Broad CP BW with low axial ratio. 3. Small antenna size (*kr*). 4. Adequate readable range.	1. Broad matching BW and Eff. 2. Low sensitivity to various circumstances. 3. Omni-directional readable range.

We employed a Pareto GA to carry out multi-objective optimization to determine detailed design parameters for the reader and tag antennas [2]. This ensured that good RFID characteristics would be achieved by the proposed antenna designs. Required characteristics for the reader antenna were the best matching bandwidth, the broader CP bandwidth, and an adequate readable range with a restricted antenna size. Optimization goals for the tag antenna were a broad matching bandwidth, stable readability under various circumstances, and omni-directional radiation gain. To achieve the aforementioned characteristics for tag and reader antennas, we used the normalized cost functions shown in Table 1.

Fig 2(a) shows the gain performance of the MPHA optimized using the cost functions. Antenna size is defined as *kr*, where *k* is the wave number at 912 MHz and *r* is the radius of the circle that encloses the whole antenna structure. The gain characteristic of the two-layered MPHA is shown to be

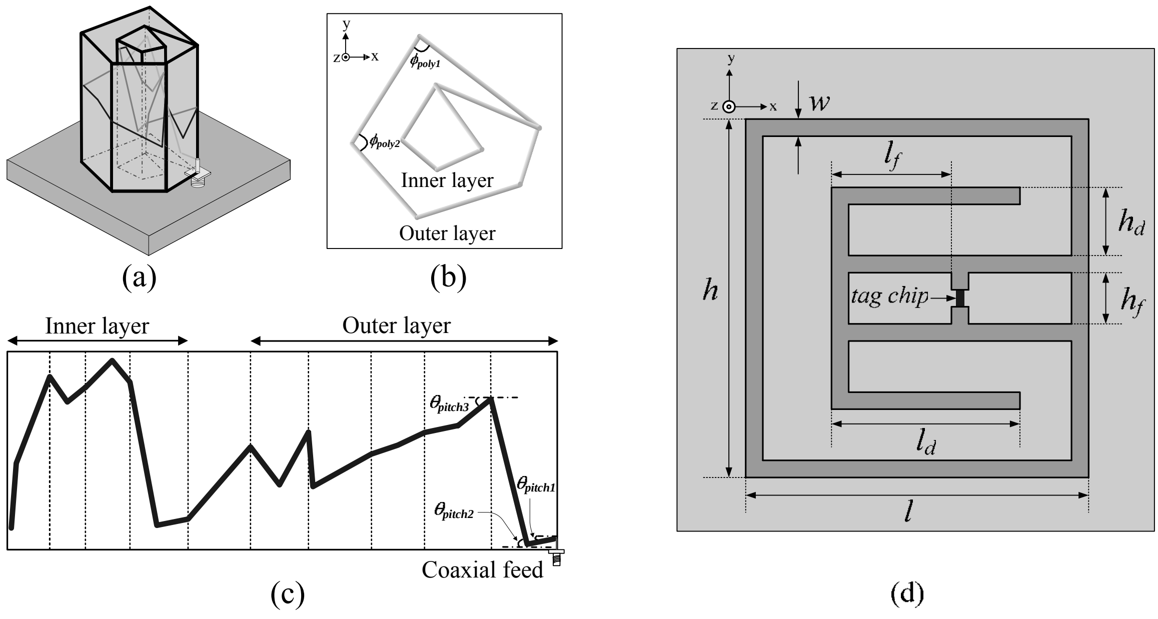


Fig 1. Configuration of the RFID antenna; (a) perspective view of the MPHA, (b) top view of MPHA. (c) unfolded structure of the MPHA, (d) top view of the omni-directional readable tag antenna.

much higher than that of the one-layered MPHA, as it approaches the theoretical gain limit [3] for the given antenna size. This demonstrates that the gain of an antenna can be easily controlled by increasing the number of layers in a MPHA, thus allowing an adequate readable range to be achieved for a given circumstance. Fig 2(b) shows the optimized results of the omni-directional readable tag antennas as the product of efficiency and bandwidth versus antenna size with the max gain deviation for arbitrary angles. A tag antenna with an excellent omni-directional pattern can be achieved when the size of the antenna is greater than about *kr*=0.76. This is because the loop in the tag antenna requires a circumference of about one wavelength for optimal operation.

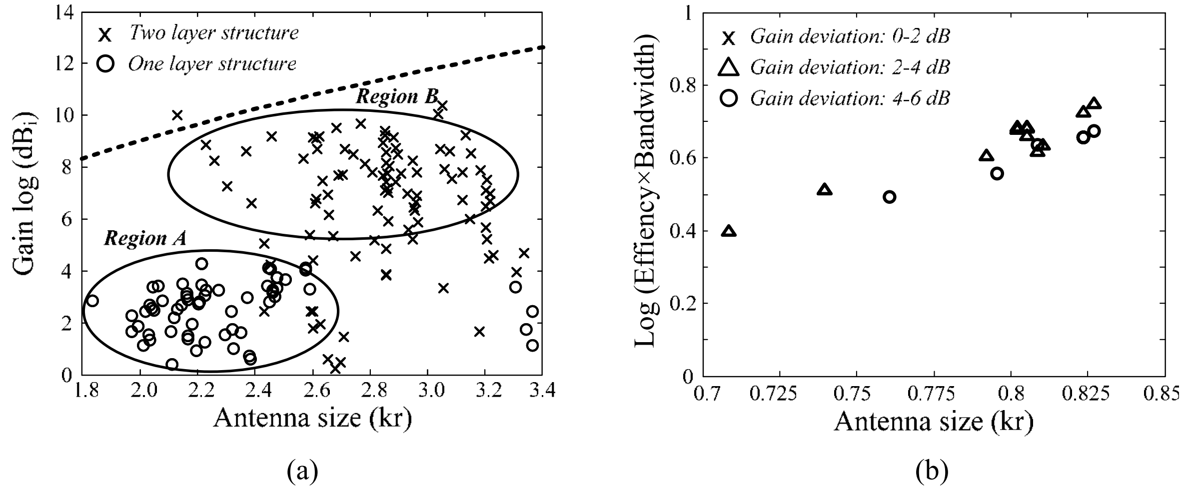


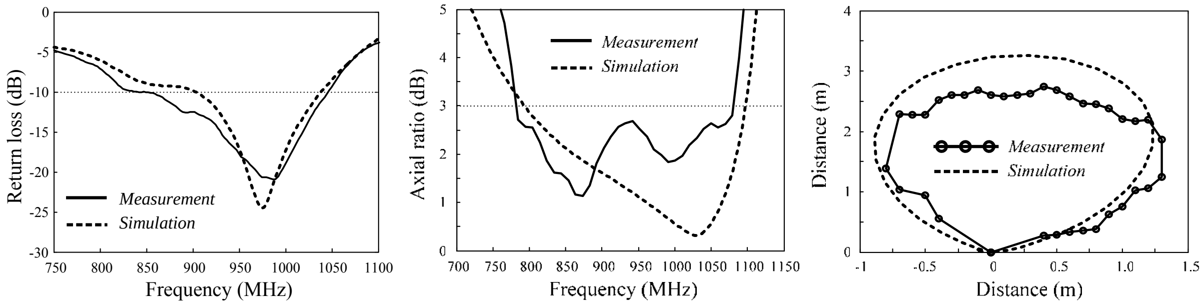
Fig 2. GA optimization results; (a) reader antenna, (b) tag antenna.

3. Antenna characteristics

To experimentally verify the optimized designs, we fabricated samples of both the reader (*kr*=3.2) and tag antennas (*kr*=0.81) with the microstrip line on cardboard (ε'=2.3, tanδ=0.22) and polyethylene (ε'=3.9, tanδ=0.003), respectively.

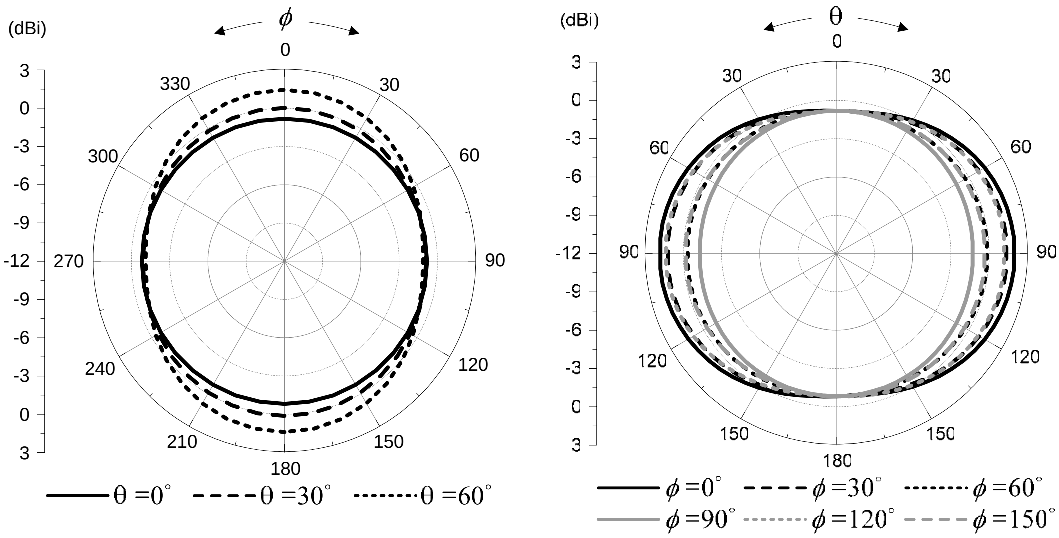
Fig. 3(a) shows the return loss of the MPHA as measured using an HP8510 network analyzer and of the simulation as determined using NEC. Measured values show the matching bandwidth of 21.38% (850~1045 MHz), referring to $S_{11}=-10$ dB, which is slightly broader than the simulated bandwidth of 15.79% (904~1038 MHz). Fig. 3(b) shows measured and simulated axial ratios versus frequency. The measured CP bandwidth (Axial ratio<3 dB) is 780~1071 MHz (31.91%), which is quite similar to the simulated CP bandwidth of 794~1097 MHz (33.2%). Although the simulations and the measurements have a similar trend, some discrepancy may be caused by fabrication-error and the loss of substrate which was not considered in the NEC simulation. We performed the simulation with a more sophisticated EM simulator, the HFSS, which is capable of correctly modeling thin substrate, and results were more similar to measured values. The measured and simulated readable ranges of the MPHA using an ALR-2850 reader [4] with an ALL-9238 tag [4], which have the radiation pattern of a conventional half wavelength dipole, are shown in Fig. 3(c). The measured readable range shows good agreement with that of the simulation except for a somewhat shorter readable range in the broadside direction.

For the fabricated omni-directional readable tag antenna, the IE3D simulator shows the half-power matching bandwidth $(S_{11}=-3$ dB$)$ of 1.7% (898.5 MHz~914 MHz) by measurement and 1.97% (902 MHz~920 MHz) by simulation. Fig. 4 shows the directive gains for arbitrary angles and it demonstrates low deviation of directive gains less than 6 dB for all angles. The omni-directional readability characteristic is verified by measuring the readable range of the tag. Results from the measurement confirm the low deviation of readable range, which is less than 31 cm (103 cm to 134 cm).



(a) (b) (c)

Fig 3 Measured results of the reader antenna; (a) impedance bandwidth, (b) CP bandwidth, (c) readable range.



(a) (b)

Fig 4. Radiation pattern of the tag antenna; (a) x-y plane, (b) y-z plane.

4. Conclusion

We investigated RFID antennas in the UHF band and proposed the multi-layered polygonal helix reader antenna and omni-directional readable tag antenna for RFID applications. We studied desirable characteristics for RFID reader and tag antennas and then optimized the antenna structures using a Pareto GA. The fabricated reader antenna with kr=3.2 exhibited 21.38% matching bandwidth, 31.91% CP bandwidth with the operating frequency of 912 MHz and a readable range of nearly 9m^2. The omni-directional readable tag antenna with kr=0.81 exhibited 1.7% half-power matching bandwidth with the operating frequency of 912 MHz and its readable distance was measured uniformly from 103 cm to 134 cm.

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[4] http://www.alientechnology.com RFID system.