Design and Development of Novel Inductively Coupled RFID Antennas

Li Yang*, S. Serkan Basat, and Manos M. Tentzeris
School of ECE, Georgia Institute of Technology, Atlanta, GA 30332-0250, USA
Email: gth772t@mail.gatech.edu

Abstract – Inductively coupled RFID antennas in two different structures, namely arc-shape and dual-body configurations, are presented. High input resistance can be easily achieved with these structures to realize conjugate impedance matching with some tag chips. 1.99dBi and 5.62dBi directivities at 915MHz are also observed.

I. Introduction

The development of RFID tags for item-level tracking of individual consumer goods has attracted great interest in recent years. Such tags have been widely considered as the future substitute technology for barcodes. For passive tags, the antenna translates electromagnetic waves from the reader into power supplied to the chip. Thus, a conjugate impedance matching between the antenna and the tag chip is highly essential to power up the chip and maximize the effective range. Inductively coupled feeding structures present one of the theoretical optimum solutions to effectively match an antenna to an arbitrary chip impedance. Several inductively coupled RFID antenna prototypes with meander line arms have been proposed in the past [1, 2]. However, the typical resistance of such antennas can hardly achieve high values in practice, limiting their use to a limit number of tag chips. Up to now, no inductively coupled antenna input resistance higher than 50Ω has been reported based on meander line arms configurations.

In this paper, a novel inductively coupled RFID antenna for 915MHz is proposed. Its arc-shape arms will effectively reduce the intrinsic resistance of the radiating body, resulting in the increase of antenna input resistance in inverse proportion. An equivalent lumped element model has been explored and utilized for the verification of this performance. Further more, an RFID antenna prototype with "dual radiating bodies" is also discussed in this paper. High directional gain is achieved with this structure, besides the required impedance performance.

II. Antenna Design and Modeling

A typical inductively coupled feeding structure is shown in Fig. 1a. The antenna consists of a feeding loop and a radiating body [3]. Two terminals of the loop are connected to the chip, and the feed is combined with the antenna body with mutual coupling. The measured impedance of the selected IC is 73-j113Ω, which means the load antenna impedance should be 73+j113Ω for conjugate matching. To achieve this, the proposed antenna structure is shown in Fig. 1b with dimensional notation. It is printed on a 2mil thick LCP substrate with ε_r=3.16. The dipole arms are bent into arc-shape.

Fig. 2 presents the lumped element model for the inductively coupled feeding structure, where R_{rb} and R_{loop} are the individual resistances of the radiating body and the feeding loop. M is the mutual inductance and L_{loop} is the self- inductance of the feeding loop. At resonant frequency, the components of impedance can be predicted in

$$Ra = \frac{(2\pi f_0 M)^2}{R_{rb}} + R_{loop} \tag{1}$$

$$Xa = 2\pi f_0 L_{loop} \tag{2}$$

R_{loop} is typically small, therefore, resistance is mainly controlled by M and R_{rb}. The reactance is dependent only upon L_{loop} [2].

R_{rb} is significantly reduced in the arc-shape configuration, resulting in higher Ra value. To verify this effect, meander line arms with the same line width and spacing were also modeled. The equivalent circuit was optimized with the ADS simulation software, so that the model data and the impedance data calculated by Method of Moment (IE3D Package) align precisely. The lumped element values are shown in Table. 1. It can be seen that only the radiating body resistance R_{rb} is significantly influenced by introducing the arc-shape structure. R_{rb} is decreased from 21.4Ω to 3.67Ω and the antenna input resistance Ra is increased from 20.5Ω to 76.4Ω, reaching the range of desired value.

Another way to achieve high resistance with inductively coupled feeding structure is to introduce extra radiating elements. A prototype named dual-body configuration is presented in Fig. 3. Two meander line arms are placed in each side of the feeding loop. The equivalent circuit element values are also listed in Table. 1. The slight decrease of M is due to the shorter coupling length. However, strong mutual coupling is now introduced between the two radiating bodies, which can be similarly regarded as in a parallel connection seen from the feeding loop. In this way, R_{rb} is significantly reduced, resulting in high resistance with meander line arms. To be noticed, in this case, the equivalent circuit model shown in Fig. 2 is rough, because it doesn't consider the mutual coupling effect between the radiating bodies.

Table. 1 Lumped element values for different inductively coupled feeding antennas

Sample	R_{rb} (Ohm)	C_{rb} (pF)	L_{rb} (nH)	L_{loop} (nH)	M (nH)	R_{loop} (Ohm)	Impedance (Ohm)
Arc-shape	3.67	0.72	42.0	21.4	3.0	0.35	76.4+j102.8
Meander line	21.4	0.57	54.3	20.3	3.3	0.1	20.5+j113
Dual bodies	0.88	0.63	48.2	20.6	2.3	0.42	72.6+j25.3

III. Results and Discussion

The impedance against frequency is plotted in Fig. 4 for the single arc-shape configuration. The resistance reaches its peak at the resonant frequency (915MHz) of the radiating body. The impedance of the proposed antenna is 76.4+j102.8Ω at 915MHz. A -22.9dB return loss is achieved at 915MHz. Since the radiating body is basically a dipole, the radiation pattern is quite similar to that of a dipole, as shown in Fig. 5. A directivity of 1.99dBi is achieved with 89.7% radiation efficiency.

For the dual-body configuration, the impedance is 72.6+j25.3Ω with -11.43dB return loss at 915MHz. Considering the input reactance is controlled by the intrinsic inductance of the feeding loop, better reactance match can be achieved by further optimization. Since the two radiating bodies are not in the same side of the feed loop, the current directions are opposite along them and the radiation patterns cancel out each other in most of the directions. Thus, in this inductively coupled RFID antenna, the radiating energy is focused directionally in a dumbbell shape and high directivity of 5.62dBi is observed with 79.9% radiation efficiency. The radiation pattern is shown in Fig. 6. Highly expanded effective range is expected to achieve with RFID antennas in such a configuration.

IV. Conclusion

In this paper, two inductively coupled antennas have been proposed for 915MHz UHF RFID applications. An analytical model has been developed to analyze the impedance feature. The presented antenna structures can supply higher resistance to realize conjugate match with some types of tag chips. Inductively coupled RFID antennas with up to 70Ω input resistance have been first time reported. Radiation properties are also presented.

References

[1] C. Cho and I. Park, "Design of UHF small passive tag antennas," *IEEE Antennas and Propagation Society International Symposium*, vol. 2, pp. 349 – 352, July 2005.

[2] H.-W Son and C.-S Pyo, "Design of RFID tag antennas using an inductively coupled feed," *Electronics Letters*, vol. 41, pp. 994 – 996, No. 18, Sept. 2005.

[3] H. Choo and H. Ling, "Design of electrically small planar antennas using an inductively coupled feed," *Electron. Lett.*, vol. 39, pp. 3080-3081, Oct. 2003

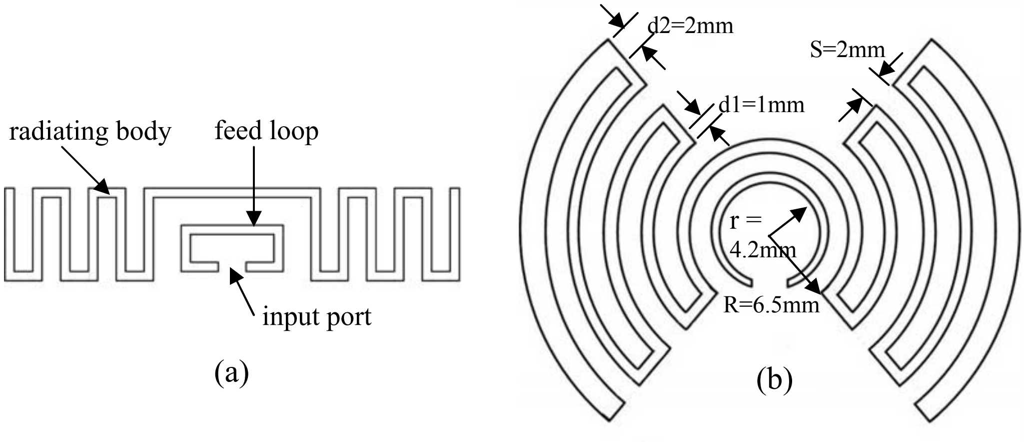

Fig. 1 Configuration of inductively coupled RFID tag antennas with (a) meander line arms (b) the proposed arc-shape arms

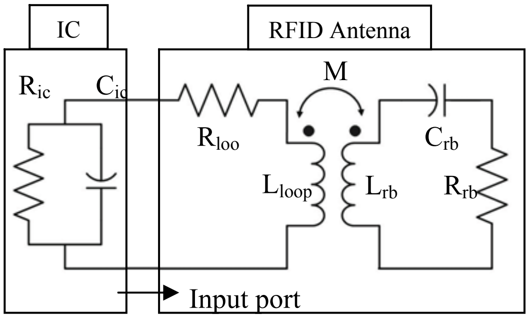

Fig. 2 Lumped element model for inductively coupled feeding RFID

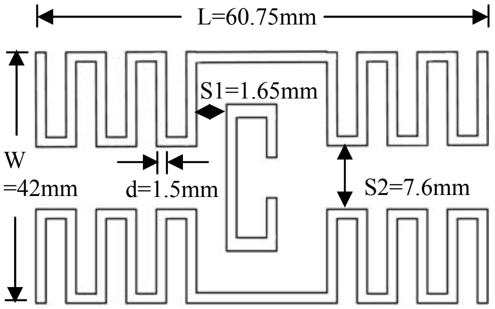

Fig. 3 Inductively coupled antenna with dual radiating bodies

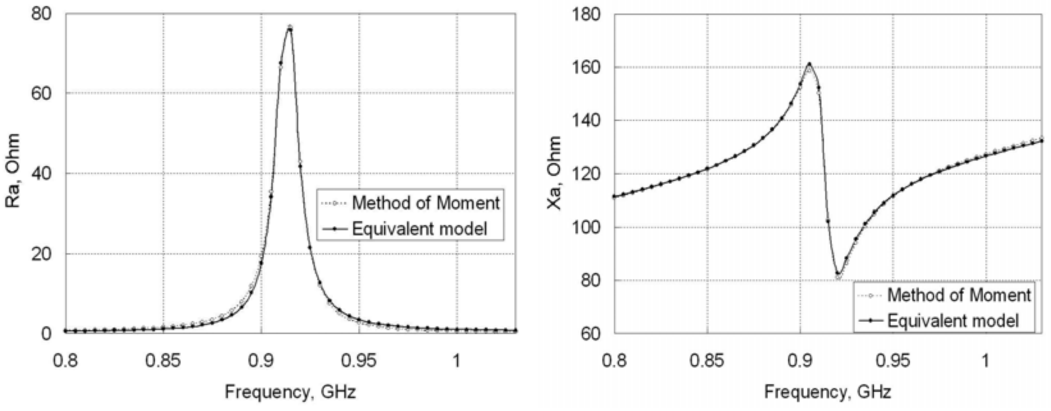

Fig. 4 Antenna impedance against frequency for the arc-shape configuration: (a) Resistance component Ra, (b) Reactance component Xa

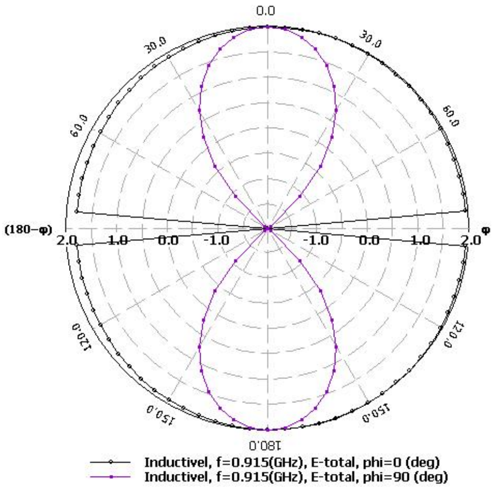

Fig. 5 Radiation pattern display of the antenna with arc-shape arms, directivity=1.99dBi

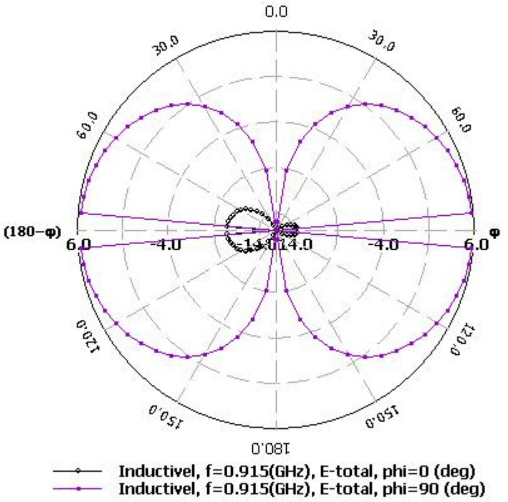

Fig. 6 Radiation pattern display of the antenna with dual radiating bodies, directivity=5.62dBi