Inductively Coupled Compact RFID Tag Antenna at 910 MHz With Near-Isotropic Radar Cross-Section (RCS) Patterns

Juno Ahn, Hyungmin Jang, Student Member, IEEE, Hyosang Moon, Student Member, IEEE, Jong-Wook Lee, Member, IEEE, and Bomson Lee, Member, IEEE

Abstract—This letter presents a compact \((0.12 \times 0.14 \lambda)\) RFID tag antenna which has near-isotropic radar cross-section (RCS) patterns and easy conjugate impedance matching property by virtue of an inductively coupled feeding. Its measured maximum and minimum RCS' are \(-17.3\ \text{dBM}^2\) and \(-20.4\ \text{dBM}^2\), respectively, with a difference of only 3.1 dB in all incident angles. The measured RCS' have been found to be in good agreement with simulation.

Index Terms—Isotropic radiation patterns, radar cross-section (RCS), RFID, tag antenna, UHF band.

I. INTRODUCTION

The fields of RFID are growing rapidly with many promising features in technology and applications, especially in the UHF band for its suitability in the middle to long range communication link between a reader and tag [1]. A tag usually consists of an antenna and microchip. By changing the terminal impedance of the microchip in two states (usually short and match), the backscattered power from the tag becomes large and small, respectively, and the digitized information stored in the chip is transferred to the reader. Since the received power at the tag (more specifically, in the chip) or reader is proportional to the radar cross-section (RCS) of the tag [2]–[4], the tag performance is best characterized by its RCS' against various incident angles from the reader. Even though many kinds of antenna structures have been proposed for RFID applications, most of their shapes are basically those of a dipole antenna [5]. In spite of their relatively simple structures and merit of low fabrication cost, the doughnut-shaped radiation patterns of dipole-type tag antennas pose some serious problems when used for RFID communication link. It is already well known that circularly polarized (CP) reader antennas are adopted to overcome the polarization mismatch problems due to arbitrary or random postures of a tag against a reader. The use of the CP reader, however, cannot completely avoid the null problems of dipole-type tag antennas. This situation occurs when they lie along the line connecting the reader and the tag. In this case, the RCS of the tag is very small or negligible (so is the received power at the reader). Since the tags are randomly oriented in most practical applications, there is, at best, a few percent of chance that the tags are not detected by a reader due to the mentioned link problem. This is indeed a crucial drawback of most commercial tags. This problem can be solved with a tag antenna with near-isotropic CP RCS patterns. In [6], a passive UHF-band RFID tag antenna using two bent dipoles and a modified double T-matching network is proposed for use as an antenna with a near-isotropic radiation pattern. Its size is 79 \(\times\) 53 mm with read range of 1.7–2.4 m for an arbitrary rotation angle of the tag. In this letter, a novel inductively coupled tag antenna which has near-isotropic RCS patterns is proposed. The proposed structure is very compact but has relatively large RCS'. It can be simply printed on a cheap PET substrate and can be easily conjugate-matched to most commercial chips of which terminal impedances are in the capacitive region, by virtue of the inductively coupled feeding method [7].

II. TAG ANTENNA DESIGN

The geometry of the proposed tag and its fabricated photograph are shown in Fig. 1(a) and (b). The tag antenna has been fabricated with a thin copper layer on PET substrate \((\varepsilon_r = 3.2)\). Since the thickness of the PET substrate is so thin that it does not affect the tag antenna impedance. Its role is simply to sustain the tag antenna structure. The overall size of the proposed tag antenna is relatively small \((40 \times 46\ \text{mm} \ 0.12 \times 0.14\lambda\) at 911 MHz) compared with that of most commercial RFID tags. The inductively coupled feeding structure facilitates realization of tag antenna impedances in the inductive region. This is required for complex conjugate matching to most chips of which terminal impedances are in the capacitive region.

The currents on the radiating element have been carefully designed to flow in the \(x\) and \(y\) directions in comparable amounts. This makes possible the near-isotropic CP RCS patterns. By adjusting the separations \([Lx4\  and\ Ly4\ in\ Fig.\ 1(a)]\) and meandered lines at the two edges of the radiation element, the required antenna impedance for a specific chip can be achieved with ease.

III. SIMULATION AND MEASUREMENT

Based on a typical high-Q (quality factor) chip impedance of \(Z = j146\ \Omega\), the designed tag antenna impedance is \(Z_A = 2 + j146\ \Omega\) at 911 MHz and the locus of the antenna impedance is shown in Fig. 2 for the frequency range of 0.5–1.5 GHz.

It is observed that the locus circles around the impedance point of \(Z_A = 2 + j146\ \Omega\) near 911 MHz. The range of chip
Fig. 1. Geometry of proposed tag antenna. (a) Tag dimensions. (b) Fabricated tag photograph.

Fig. 2. Loci of tag antenna impedance.

resistance found in the literature is about $2 \sim 12 \Omega$ and that of chip reactance is about $-150 \sim -100 \Omega$. The quality factor $Q$ for a combined system of tag and chip is roughly the ratio of chip reactance and resistance. The $Q$ factor of the proposed tag antenna is thus about 75. Most commercial chips being developed these days have high $Q$ factors to lower the required threshold open-circuit voltage of the tag [8]. The difference of $Q$ factor for the two chip impedance states is about 5.06 $\Omega$. The $Q$ factor must be lowered by reducing the ratio of chip reactance and resistance at an initial design stage. A tradeoff is usually necessary between the required $Q$ factor for the chip and RCS bandwidth. The used EM simulator is Microwave Studio 5.1.

We show in Fig. 4 the RCS measurement setup. The Tx and Rx antennas are connected with a network analyzer. The RCS of the tag are obtained by comparing the measured value with that of a standard shorted dipole antenna, of which RCS is $-10.3 \text{dBi}^2$. A standard SOLT calibration of the network analyzer without the tag is also necessary to alleviate the isolation problem due to direct leakage of the Tx RF signal to the Rx antenna. This seems to be a better method than that used in [3]. In [3], the isolation problem is not addressed properly. In Fig. 5(a), (b), and (c), we show the simulated and measured CP RCS in XZ, YZ, and XY planes. The simulated RCS have been obtained for the two cases of the chip loads, (short) and (match), and are plotted as a function of incident angles. The RCS’ have also been measured at every 30 degrees only for the chip load of (short) for comparison purpose. For the required reactance of $Z_L = -j146 \Omega$ (short) at 911 MHz, a chip capacitor with capacitance of 1.2 pF was mounted in the place of a tag chip as shown in Fig. 1(b). The
The measured maximum RCS is $-17.3$ dBm$^2$, minimum RCS is $-20.4$ dBm$^2$, and their difference is only $3.1$ dB. This is an excellent improvement compared with cases of dipole-type tags of which typical RCS differences are as much as $70$–$80$ dB. This null problem of the existing dipole-type tags is considered to be responsible for a several percent of statistical detection errors commonly found in a RFID link when a tag is arbitrarily postured against a reader. The proposed compact tag antenna having near-isotropic RCS patterns has been shown to be capable of solving this long-standing problem and will contribute to a more reliable RFID system.

### IV. CONCLUSION

A compact $(0.12 \times 0.14\lambda)$ RFID tag with inductively coupled feed and near-isotropic RCS patterns has been designed, fabricated, and measured. The targeted tag antenna impedance, usually in the inductive region, is easily tailored with a simple adjustment of the tag dimensions. The difference of the measured maximum and minimum RCS in all incident angles against the proposed tag is only $3.1$ dB, which is a significant improvement compared with those of usual dipole-type RFID tags. This feature is expected to solve the null problems of most commercial tags and enable a more reliable RFID communication link between a reader and tag.

### REFERENCES