ELECTRICALLY SMALL ANTENNA FOR RFID AND WIRELESS SENSOR TRANSPONDERS

Yuri Tikhov, Yongjin Kim, and Young-Hoon Min
Samsung Advanced Institute of Technology, P.O. Box 111, Suwon 440-600, Korea
E-mail: tikhov@sait.samsung.co.kr

This work discloses a novel electrically small planar antenna for microwave RFID and Wireless Sensor passive transponders. The proposed antenna takes advantage of its unique topology in order to assure conjugate matching with essentially complex impedance of the electronic chip directly embedded into radiator. Very good performance is predicted theoretically and confirmed experimentally over an operating bandwidth of actual RFID system.

1. Introduction

A recent solid market research predicts that worldwide revenues from Radio Frequency Identification (RFID) transponders will jump from $300 million in 2004 to $2.8 billion in 2009 [1]. RFID transponder is a tag device that can respond by sending a content of its embedded memory by backscatter communication to interrogator (reader). A passive RFID transponder has no battery, instead it gets all the needed energy from the carrier signal of the reader. A passive Wireless Sensor device also generates its electrical operating power by rectifying the RF voltage delivered by the antenna.

Generally, the transponder comprises an Application Specific Integrated Circuit (ASIC) connected to an antenna. Low cost planar antennas for RFID tags with substantially small electrical size are strongly focused in recent years. Because nowadays, the antenna size of even a quarter wavelength is precluded in many applications.

Theoretical aspect of antenna miniaturization trace back to the 1940s [2-3] and 1960s [4]. These early studies show that small antennas are constrained in their behaviour by a fundamental limit: the smaller the maximum dimension of the antenna, the higher is its Q, or equivalently, the narrower is its bandwidth. The computation of the smallest possible Q for a linearly polarized antenna was refined in [5]. Accordingly, the art of antenna miniaturization is always an art of compromise among size, bandwidth, and efficiency (gain). In the case of planar antenna, good compromise is usually obtained when most of the given area of antenna strongly participates in the radiation phenomenon.

The authors have recently introduced a novel radiator for small planar antennas that can operate over enhanced bandwidth without any affect on radiation pattern, gain, and polarization purity [6]. However the implementation of radiator [6] into RFID transponder design now faces another challenge. The matter of fact is that ASIC has essentially complex input impedance with substantial capacitive reactance. Therefore the problem of complex conjugate matching between tag antenna and ASIC should be solved over operating bandwidth of the system.

In this paper our idea of small planar radiator [6] is extended to its transponder realization. We propose a new configuration of small antenna that can be effectively matched with direct inlet of ASIC chip into radiator.

2. Antenna Structure and Conjugate Impedance Matching

Impedance matching between transponder ASIC and antenna is critical on overall RFID and Wireless Sensor system performance. Namely the mismatch very strongly affect a read range – a maximum operating distance between interrogator and transponder. Because the power radiated by interrogator is rather limited due to certain safety regulations and other legislation. And passive transponder extracts its operating power by rectifying interrogation signal delivered by the antenna.

Rectifier circuit is a part of ASIC and comprises diodes (such as Schottky diodes) and capacitors, resulting in the complex input impedance with substantial capacitive reactance. Typically the impedance of ASIC comes to a few or tens of active Ohms and a few hundreds of reactive (capacitive) Ohms. Thus the ratio of the reactance to the resistance is very high.

One conventional matching technique in such a situation is an implementation of additional separate matching circuit based on inductors. However, a conventional way is now problematic

ISBN: 89-86522-79-9 94460©KEES

because it unacceptably increases production costs. Moreover, a separate matching circuit causes extra losses that eventually also strongly reduce system performance. Consequently, the antenna impedance should be matched directly with ASIC of the transponder.

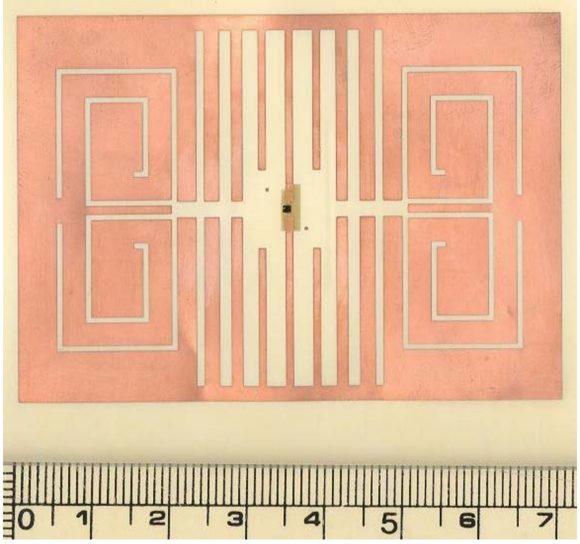

Fig. 1. Photograph of assembled transponder.

The photograph of realized UHF transponder is shown in Fig. 1. ASIC has been flip-chip bonded directly into radiating element of the antenna. ASIC can be seen as a centrally placed dark spot in Fig. 1. The antenna itself comprises a thin copper layer formed on a surface of thin flexible dielectric substrate, and a slot pattern within that copper layer.

The key idea how to reduce effectively the size of antenna has been reported in detail recently [6]. Since the overall required size of antenna is substantially less than a quarter wavelength, the length of the main slot is all the more so shorter. Therefore, in order to achieve required size reduction, a specific value of finite voltage at both ends of the main slot should be imposed. Thereby the desired resonant field distribution on shorten main slot can be situated. To arrange the desirable voltage discontinuity at the ends of the main slot the terminating elements should possess inductive properties. According the idea of Azadegan and Sarabandi [7], the termination could be arranged by two straight or turn slot elements. And as shown in Fig. 1, in contrast to conventional structures, our slot pattern is configured with four convoluted slot arms terminating a main slot at each of both its ends. Importantly, one pair of terminating slot arms is convoluted clockwise while another pair is convoluted counterclockwise. The slot arms are further formed as mirror-symmetrical couples with respect to the main slot line. The clockwise and counterclockwise convolute slot arms provide the antenna with unique electromagnetic features [6].

In order to enhance inductive properties of antenna as seen at feeding point the system of additional transverse slots with respect to the main radiating slot has been created (Fig. 1). The comparable idea of distributed inductive loading was described in [8] but in a different context of miniaturization of conventional 50-Ohm fed antennas.

The combination of transverse slots and convolute slot arms provides the small antenna with specified ratio of inductive reactance to the resistance. Thereby it assures conjugate matching between antenna and ASIC of passive RFID transponder over operating bandwidth.

3. Measurement

Measurements of electrically small antennas are basically impeded because every sort of cable connection between antenna and Network Analyzer generally disturbs the field near the antenna. Such field disturbance is very severe in the case of antennas with non-traditional feeding by means of direct chip inlet into small radiator. Consequently special measures are required to obtain sufficiently accurate experimental verification of transponder antenna.

Fortunately, the proposed antenna possesses electromagnetic two-plane symmetry. Neglecting two marking small dots for flip-chip bonding process, there are both E-plane and H-plane symmetry in the structure (Fig. 1). Actually those two planes of symmetry are effectively used in order to reduce necessary computer resources, especially memory and CPU-time, for electromagnetic simulation of the antenna by commercial finite-element tool HFSS [9]. Now E-plane symmetry has been used for measurement of antenna impedance. Namely, instead of measurement of full antenna, a half of antenna structure has been measured with metal plate of substantial electrical size replacing the E-symmetry-plane. The impedance of a half-antenna with metal plate amounts to a half of impedance of the full antenna.

The photograph of the measurement setup is shown in Fig. 2. The metal plate is composed of a stainless steel part (1m x 1m) and a brass part (16cm x 16cm). The composition of two parts is chosen for convenience of assembling with replaceable features of small brass part. The cable of Network Analyzer is hidden under the metal plate.

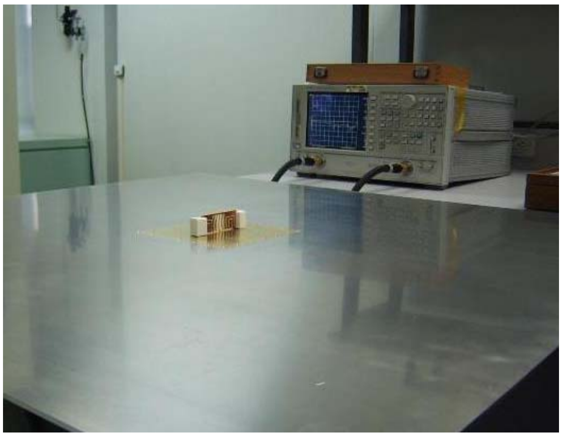

Fig. 2. Measurement setup.

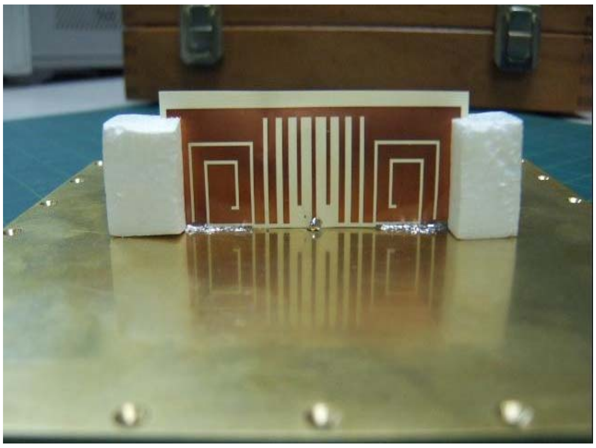

Fig.3. Half-antenna mounted on the metal plate.

The adjacent metallization of antenna is soldered to brass plate as shown in Fig. 3. The feeding point of antenna is soldered to a central pin of SMA connector. The pin of SMA connector passes through the circular hole in the plate thereby forming a small 50-Ohm section of coaxial line. Since the antenna possesses a mechanical flexibility it has been fixed in normal position to metal plate by two foam posts. The dielectric permittivity of the foam material is close to one of air, so the posts almost do not affect electromagnetic field distribution.

The measurements have been performed with Agilent 8722ES Network Analyzer. It should be noted that Network Analyzer has been pre-calibrated without input SMA connector of the test structure. So the reference plane is somewhat below the surface of the metal plate. Besides the coaxial connector itself superinduces capacitive reactance into the object under test. Therefore resulting resonant frequency must be shifted down. The effect of additional reactance and shift of reference plane has been simulated by HFSS [9].

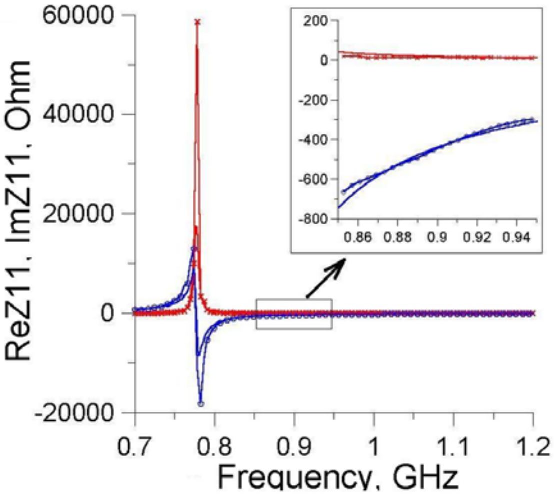

Fig. 4. Comparison between simulated and measured impedance of test structure:
symbols – measurement,
solid lines – simulation.

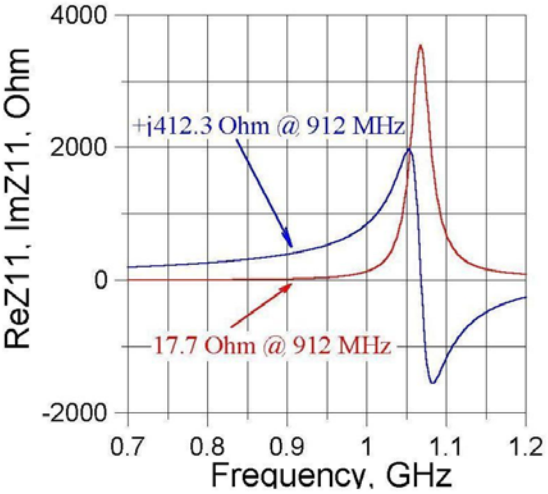

Fig. 5. De-embedded impedance of half-antenna.

Fig. 4 shows a comparison between simulated and measured results. Excellent agreement between theoretical prediction and experiment is observed. Fig. 5 shows the half-antenna impedance after de-embedding of reference plane and parasitic reactance of the SMA connector. It can be observed that if double both real and imaginary part of impedance of half-antenna (17.7+j412.3 Ohms @ 912 MHz) those are very close to complex impedance of designed full antenna.

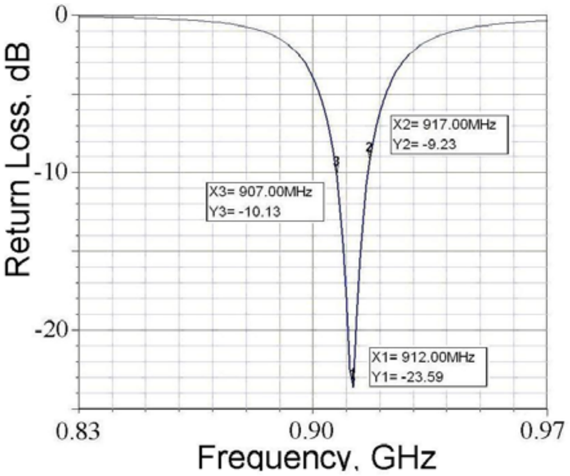

Fig. 6. Simulated return loss of full antenna terminated by ASIC chip of RFID transponder.

The simulated return loss of full antenna if loaded by specified impedance of actual RFID tag chip is shown in Fig. 6. It has been assumed that complex impedance of the chip is constant 35-j816 Ohm. It is observed that achieved operating bandwidth of the antenna is 10 MHz (1.1%) at the level of –10dB return loss.

Actual overall size of antenna is 7cm x 5cm. It amounts to $0.21\,\lambda_0 \times 0.15\,\lambda_0$, where λ_0 is the wavelength in a free space at the center frequency of 912 MHz.

Of course, since antenna is electrically small, the radiation pattern is of omni-directional type and the polarization is linear. The level of a cross-polarization is negligible.

The simulated radiation efficiency amounts to 75 percent and takes into account both metal and dielectric losses.

It should be noted that for the backscatter communications the radar cross section (RCS) of antenna is very important, because a modulated RCS is essentially used for the transmission of data from a transponder to a reader. In the case of co-polarized normal incident wave the RCS of proposed antenna at 912 MHz amounts to 38.4 centimeter squared at conjugate matching versus 6.5 centimeter squared at short-circuit termination. Thereby is assures effective modulation of RCS.

4. Conclusion

A novel small planar antenna has been proposed for passive transponder. The antenna impedance has been directly conjugate matched with essentially complex impedance of the electronic chip inlet over the 1.1% bandwidth. Precise prototyping and accurate measurements guarantee a veracity of the results. The area of application includes RFID, Wireless Sensor, and other perspective short-range wireless systems.

ACKNOWLEDGEMENT

The authors would like to thank the SAIT team members: Mr. Il-Jong Song, Dr. Donghyun Lee, and Mr. Janam Ku for their important work in part of ASIC characterization and valuable discussions.

REFERENCES

[1] A. Nogee, “RFID tags and chips,” *RFID Journal*, www.rfidjournal.com, pp. 1-2, Jan. 2005.
[2] H.A. Wheeler, “Fundamental limitations of small antennas,” *Proceedings of the IRE*, vol. 35, pp. 1479-1484, Dec. 1947.
[3] L.J. Chu, “Physical limitation on omni-directional antennas,” *Journal of Applied Physics*, vol. 19, pp. 1163-1175, Dec. 1948.
[4] R.F. Harrington, “Effect of antenna size on gain, bandwidth and efficiency,” *Journal of Research of the National Bureau of Standards – D. Radio Propagation*, vol. 64D, pp. 1-12, Jan.-Feb. 1960.
[5] J.S. McLean, “A re-examination of the fundamental limits on the radiation Q of electrically small antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 44, pp. 672-676, May 1996.
[6] Y. Tikhov, Y.J. Kim, and Y.H. Min, “A novel radiator for small planar antennas,” in *Proceedings of Asia-Pacific Microwave Conference,* APMC2004, New Delhi, India, pp. 168-173, December 15-18, 2004.
[7] R. Azadegan and K. Sarabandi, “A novel approach for miniaturization of slot antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 51, pp. 421-429, Mar. 2003.
[8] N. Behdad and K. Sarabandi, “Bandwidth enhancement and further size reduction of a class of miniaturized slot antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 52, pp. 1928-1935, Aug. 2004.
[9] High-Frequency Structure Simulator, HFSS v. 9.2, trademark of Ansoft Corporation, Four Station Square, Pittsburgh, PA 15219-1119, USA.