3D RFID Transponder Antennas for Smart Packaging Applications

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Abstract

During the recent years we observe a growing number of smart packaging applications. Within this field radio frequency identification (RFID) technology contributes remarkably to the progress by providing the matching communication / data transmission opportunities. In order to employ RFID technology for packaging applications the availability of highly functional RFID transponders (antenna + silicon chip) is necessary, which satisfy a maximum of communication reliability and reading distance. We report on a significant improvement of the performance of existing transponder systems by the introduction of three dimensional (3D) antennas which can be printed cost efficient directly on the planar packaging material and become three dimensional in the folding step of erecting a cardboard box. These 3D antennas for different frequency ranges, each particularly designed regarding layout and dimensions of the package and its content open a wide range of reliable packaging applications and therefore contribute remarkably to the development of the "internet of things".

Introduction

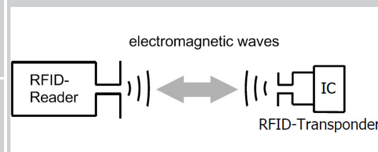
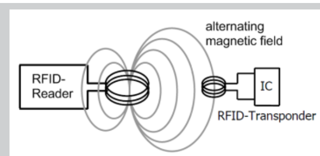
Employing printing processes (gravure, screen printing, inkjet and flexo) for manufacturing different RFID transponder antennas is state of the art [1], [2], [3] but until today large-scale commercialization / applications of printed RFID transponder technologies are still missing. Two mayor reasons for a slower introduction of the passive tag technology than forecasted [4] are the costs of the transponder chip and the rather poor communication reliability between transponder and reader [3].

This paper reports on research results contributing to the enhancement of communication reliability and communication quality of RFID transponders integrated in smart packaging applications by printing techniques.

Basics

Radio Frequency Identification Systems allow wireless transmission of data / signals utilizing two different RF coupling technologies in different frequency bands. Most of the state of the art applications are based on alternating magnetic fields @ 125 kHz and 13.56 MHz. A gain in communication quality is achieved by electromagnetic wave coupling @ 868-928 MHz, 2.45 GHz and 5.8 GHz (comp. table 1). Both techniques have advantages and disadvantages and therefore they are handpicked depending on the application. The approach on which we report here focuses on RFID transponder antennas for passive tags working at 5.8 GHz, a legally attested future communication frequency with promising prospects of success. This frequency was chosen to extend the reading range remarkably and to improve the communication reliability and communication quality simultaneously.

Table 1: RFID technology overview

RFID resonance frequency	kind of signal link-up	reading distance
5.8 GHz		approx. 30 m
868 MHz		8 - 10 m
13.56 MHz		10 cm
125 kHz		1 cm

For the signal transmission via electromagnetic waves, generally dipole antenna structures are employed. These antenna structures show omnidirectional (donut shaped) radiation characteristics (comp. figure 1) with the consequence that significant parts of the antenna radiation is emitted in the direction of the inner cardboard box which might be filled with challenging dielectric material. This results in absorption, reflection and diffraction effects of the emitted electromagnetic waves which are fed back into the antenna and so negatively influence the functionality and communication reliability of the transponder [5].

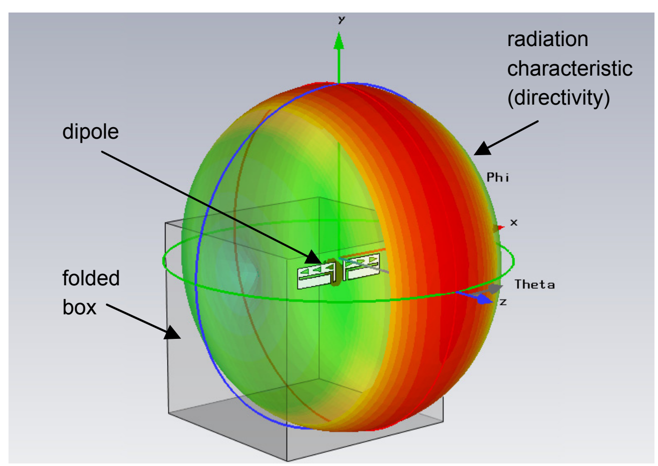


***Figure 1**: Simulation result - dipole antenna radiation characteristic*

In order to improve the communication reliability and communication quality, it is necessary to develop transponder antennas which have a directional radiation characteristic without signal emission into the interior of tagged cardboard box.

Results

A three dimensional antenna structure was designed (see. figure 2) in order to implement a radiation directionality which does not cover the interior of the box. This antenna consists of two dipole arms which are positioned perpendicular to each other. Thus, it is easy to integrate the antenna in the corner of a rectangular package.

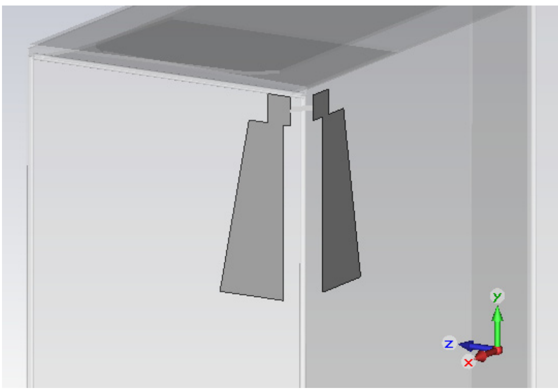


***Figure 2**: 3D antenna design*

The radiation behavior of the 3D antenna arrangement was calculated with the simulation software CST Studio Suite (comp. figure 3). It is shown that the radiation behavior is focused into two directions (red areas in figure 3).

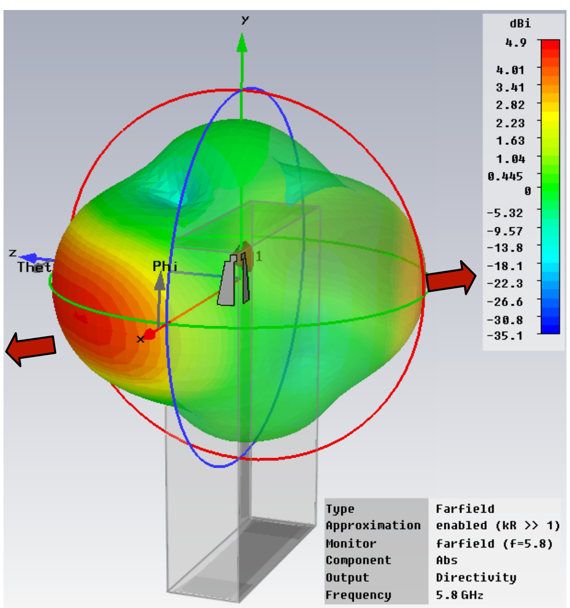


***Figure 3**: Simulation of the 3D antenna radiation characteristic, carried out with CST studio suite*

Accordingly, only a very small portion of the electromagnetic waves are emitted into the interior of the package. Consequently, reflection and diffraction effects of the electromagnetic waves are minimized and communication reliability and communication quality is remarkably increased.

In addition to the advanced functionality of the new 3D antennas we intend to optimize the manufacturing costs. Given the fact that their design strongly depends on the geometry and content of the package the established business model for RFID labels (extremely high number of identical labels designed for a broad range of different applications) needs to be reconsidered.

The application of conducting material on 3D objects was reported recently [6] but this technology requires rather complex manufacturing processes and equipment. Therefore we propose to print an appropriate conducting ink (e.g. Ag or Cu based) on the backside of the planar signature of a package and transform it into a 3D object / antenna in the step when the printed sheet becomes a box by folding the signature.

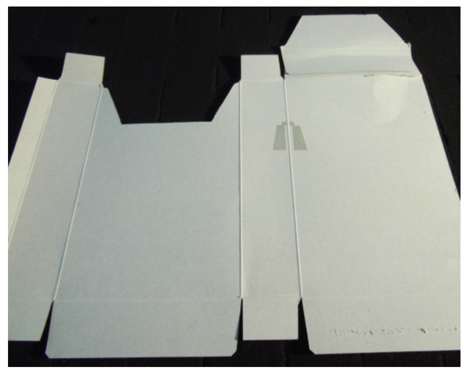


***Figure 4**: Printed 3D antenna on a planar, unfolded signature of a cardboard box*

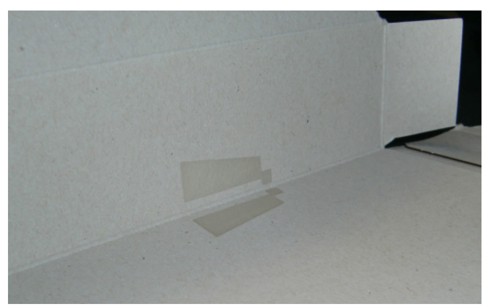


***Figure 5**: Printed 3D antenna on a folded / erected cardboard box*

The antenna shown in figures 4 and 5 was manufactured on cardboard by screen printing a silver paste (Sun Chemical CRSN2442) and using a polyester screen (195 meshes). The silver layer was dried for 15 minutes in a vacuum oven at 110°C.

These printed and folded 3D antennas were analyzed in an anechoic chamber, a interference-free Faraday cage. For measuring the radiation characteristic and directivity, the antenna was rotated in azimuth direction angle and elevation angle. Thereby the direction dependent coupled signal strength was measured with a spectrum analyzer (ZVL6 Rohde & Schwarz). The Friis link equation [7] was utilized to calculate the antenna directivitiy from the measured signal strengths. To visualize the calculated directivity we employed again CST Studio Suite. The result is presented in Fig. 6, demonstrating a rather clear agreement of simulation and experiment.

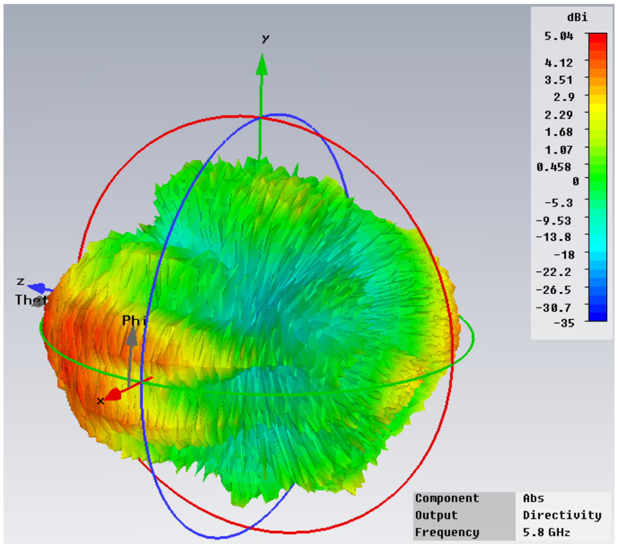


***Figure 6**: experimentally determined 3D antenna radiation characteristic, calculated by Friis link equation from measured values*

Summary

We have shown that 3D RFID transponder antennas for packaging applications can be designed and adapted in terms of the highest standards of communication reliability and communication quality. Moreover, the printing-based manufacturing process of the 3D RFID transponder antennas is extremely cost-effective since planar printing techniques were employed and the 3D object / antenna is generated by folding the printed sheet to a three dimensional cardboard box . This general, new method for manufacturing 3D antennas can also be employed for appropriate applications in other RFID frequency ranges as 868 MHz or 2.4 GHz.

References

[1] T. Björninen, S. Merilampi, L. Ukkonen, L. Sydänheimo, and P. Rususkanen, “Effect of Fabrication Method on Passive UHF RFID Tag Performance,” International Journal of Antennas and Propagation (2009) Article ID 920947

[2] L. Yang, A. Rida, R. Vyas, and M. M. Tentzeris, “RFID Tag and RF Structures on a Paper Substrate Using Inkjet-Printing Technology,” IEEE Transactions on Microwave Theory and Techniques, Vol. 55, No. 12, (2007)

[3] R. Zichner, F. Siegel, and R. R. Baumann, Communication Quality of printed UHF RFID Transponder Antennas, Proc. LOPE-C, pg. 361 – 363. (2011)

[4] P. Harrop and R. Das, “Printed and Chipless RFID Forecastes, Technologies & Players 2009 – 2029”, IDTechEx Report, pg. 7 (2009)

[5] R. Zichner and R. R. Baumann, Customized Printed RFID Antennas for Various Environments, Proc. LOPE-C, pg. 09·1 - 09·4. (2009)

[6] J. J. Adams et al., “Conformal Printing of Electrically Small Antennas on Three-Dimensional Surfaces,” Advanced Materials, (2011)

[7] David M. Pozar, Microwave Engineering (Third Edition, John Wiley & Sons, 2005) pg. 647 – 648

Author Biography

Ralf Zichner holds a Diploma in Electrical Engineering. 2007-2008 he was a research assistant at the department for High Frequency Technology and Photonics and at the department of Digital Printing and Imaging Technology (both of Chemnitz University of Technology). In 2009 he moved to the department Printed Functionalities of the Fraunhofer Institute for Electronic Nano Systems ENAS, Chemnitz. His research focuses on design, simulation, printing and experimental analysis of Radio-Frequency components.