RFID Tag Antenna Design for ARC Specs

Pavel Nikitin, John Kim, KVS Rao
Impinj, Inc
Seattle, WA, USA
pnikitin@impinj.com, jkim@impinj.com, krao@impinj.com

***Abstract*— In this paper, we explain how to design a UHF RFID tag antenna for ARC requirements, which are industry tag certification specifications. We focus on a 50 mm x 30 mm tag design that passes specs A through I. We explain how to model tag performance on complicated items that are part of ARC specs (such as jeans), and present modeling and simulation results which are in good agreement with measured data.**

Keywords—RFID tags; radiofrequency identification; antennas

I. INTRODUCTION

RFID is a technology with a long history [1], and UHF RFID (also known as RAIN RFID [2]) is a major part of it. It should be noted that higher frequency bands can also be used for long range passive RFID [3] but the prevailing standard is currently using UHF band (860-960 MHz). Many papers on various tag designs have been published in the last 20 years, but most of them concentrate on tag antenna design for a specific application, such as for specific dielectric materials [4-7].

At the same time, RFID industry places paramount importance on tags that are designed to meet ARC specs. ARC is a tag certification program [8] which ensures that RFID tags applied to pre-defined items meet or exceed the retailer's performance requirements. ARC keeps a database of tags available on the market that pass certain ARC specs. ARC currently has 20 published specs.

Tag performance can be characterized by threshold tag sensitivity, also called threshold POTF (Power on Tag Forward) and tag backscatter, also called POTR (Power on Tag Reverse) which depends on incident RF power level (i.e. POTF). ARC specs A through I are summarized in Table I which states minimum required POTF and POTR (at that POTF) on certain items (FM is foam, CS is cardstock, PB1 is one polybag, PB2 is a stack of two polybags, J1 is one pair of jeans, J2 is a stack of two pairs of jeans, and J10 is a stack of ten pairs of jeans).

ARC and its database make it easier for companies to deploy RFID because they can select from the database of existing tags the ones that meet their needs. There is no size restriction in ARC specs but there is a cost pressure on each tag manufacturer to meet maximum number of specs using a tag of smallest possible size. Besides the form factor, the challenge of tag design for these specs is that some ARC test materials are not ordinary solid dielectric materials but rather items like bags of polyester shirts, stacks of jeans, etc. This aspect makes electromagnetic modeling and simulation of tags on those materials a challenging work.

In this paper, we explain how to design a UHF tag antenna for ARC specs, including modeling and simulation of tag antennas using standard dielectric materials that can be used to approximately model the effect of ARC items on RFID tags.

TABLE I. TABLE OF ARC SPECS, IN DBM (POTF AND POTR).

Band	Spec	FM	CS	PB1	PB2	J1	J2	J10
FCC	A	**-7.5**				**-11**	**-11**	**-11**
FCC	B	**-7.5**	**-11**	**-9**	**-12**			
FCC	C		**-13.5**					
FCC	D		**-11**					
FCC	F		**-11** **-29**				**-13** **-26.5**	**-11**
FCC	G		**-10** **-28**				**-10** **-26.5**	**-8.5**
ETSI	I		**-11** **-26**	**-11**	**-13**		**-13**	**-13**

II. TAG DESIGN AND MEASUREMENTS

As an example, let us design a 50 mm x 30 mm tag antenna with Monza R6 IC [9] that meets specs A through I. The tag geometry is shown in Fig. 1. We use a common UHF RFID tag antenna geometry, inductive loop coupled to matched dipole. The dipole is meandered to minimize its long dimension and has widened ends that reduce its sensitivity to the materials. Impedance matching technique using such loop (also known as T-matching [10-11]) provides a good broadband match between the antenna and the IC.

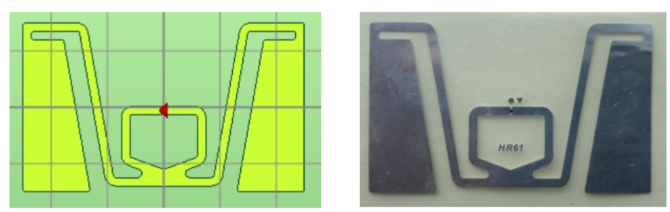

Fig. 1. Tag CST model (left) and prototype (right).

The first challenge of tag design for ARC specs is being able to simulate tag performance on tagged items. Let us concentrate on just two important limiting cases: tag on cardstock and tag in the middle of two pairs of jeans. The second case is similar to a stack of ten pairs of jeans, both of which are the most tag detuning situations compared to all other materials in Table I.

Voyantic [12] offers a set of reference dielectrics with known properties. One of those materials is cardboard. We used its properties to simulate thin ARC cardstock. By testing tags on other dielectrics from that set, on ARC items, and by comparing the results, we found that POM plastic (polyacetal) can be used to approximate tag detuning due to a stack of two pairs of jeans reasonably well, as can be seen in Fig. 3. We used those materials for tag antenna EM simulations using CST [13].

Our tag measurement setup is shown in Fig. 2. Test equipment (Voyantic Tagformance Pro) is connected to a broadband patch antenna. Tag is placed on the item of interest on the foam stand inside an anechoic chamber. The stand can be rotated by a motor if needed to test tag from different directions. We test tags from their worst antenna gain direction (normal to the axis of the dipole). We also use the most restrictive values of ARC specs (full specs list values for four different angular interrogation directions).

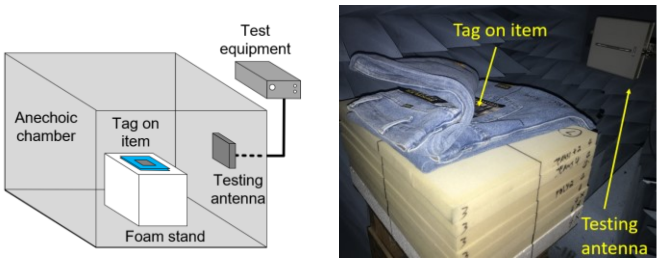

Fig. 2. Tag measurement setup

The second general challenge of tag design for a given footprint is antenna optimization. Key design parameters for the antenna geometry shown in Fig. 1 include the dipole resonant frequency, the loop inductance, and the coupling between the loop and the dipole. Another important parameter is trace width which represents a tradeoff between antenna losses and its ability to achieve longer electrical length with less physical length. Because all antenna elements are coupled to each other, there exists an interaction between all the design parameters.

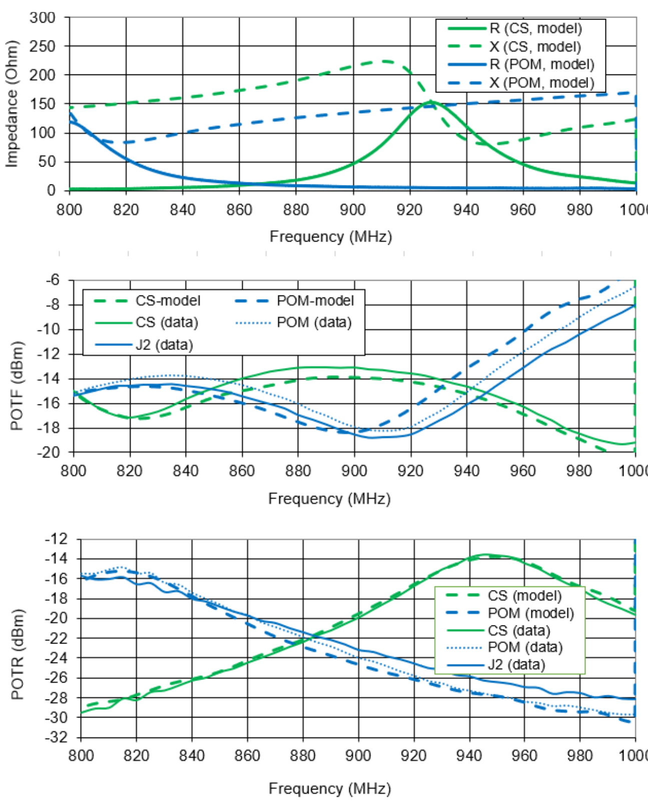

Fig. 3. Modeled and measured tag performance on cardstock (CS), polyacetal dielectric (POM), and stack of two jeans (J2).

We optimized our tag by exploring and adjusting the parameters above. For each antenna simulation run on cardstock and jeans (modeled as POM), we computed the worst values of POTF and POTR (in direction normal to the axis of the dipole) in appropriate bands (865-868 MHz for ETSI and 902-928 MHz for FCC) using well known equations [14]:

$$POTF = P_{th}/(G \cdot \tau) \quad , \quad POTR = POTF \cdot K \quad (1)$$

where P_{th} is the IC threshold sensitivity, τ is the tag impedance matching coefficient, G is the gain of the tag antenna, and K is the tag backscatter factor.

Our simulation results were in good agreement with measurements. We continuously compared modeled values to the specs until we reached a design that satisfied and exceeded the requirements on cardstock and POM. At that point, several prototypes were produced, measured, and iterated until specs for the other items were satisfied too. Fig. 3 shows the comparison between modeled and measured threshold POTF and POTR of the final tag design (dry inlay version) placed on cardstock, on POM dielectric, and inside a stack of two pairs of jeans (for simplicity of illustration, IC autotune is off in those plots).

III. Conclusions

In this paper, we described and explained the process of UHF RFID tag antenna design for ARC specs, including simulation of ARC items using standard dielectrics. We presented a 50 mm x 30 mm tag antenna design for Monza R6 that meets specs A through I. We hope that this paper will be useful and helpful to a wide audience of RFID tag antenna designers wo want to better understand ARC requirements and to design better tags for wide range of industries (retail, etc.) that use RFID technology.

References

[1] J. Landt, "The history of RFID," IEEE Potentials, vol.24, no.4, pp. 8- 11, Oct.-Nov. 2005

[2] RAIN RFID Alliance, https://rainrfid.org/

[3] P. Nikitin, J. Ensworth, KVS Rao, A. Pesavento, J. Kim, "2.4 GHz passive Gen2 RFID system" (poster), IEEE RFID 2019, Phoenix, AZ

[4] K. V. S. Rao, P. V. Nikitin and S. Lam, "Antenna design for UHF RFID tags: a review and a practical application", IEEE Transactions on Antennas and Propagation, vol. 53, no. 12, pp. 3870-3876, Dec. 2005

[5] J. D. Griffin, G. D. Durgin, A. Haldi and B. Kippelen, "RF tag antenna performance on parious materials using radio link budgets," IEEE Antennas and Wireless Propagation Letters, vol. 5, pp. 247-250, 2006

[6] G. Marrocco, "The art of UHF RFID antenna design: impedance-matching and size-reduction techniques," IEEE AP Magazine, vol. 50, no. 1, pp. 66-79, Feb. 2008

[7] S. Shao, R. J. Burkholder and J. L. Volakis, "Design approach for robust UHF RFID tag antennas mounted on a plurality of dielectric surfaces," IEEE AP Magazine, vol. 56, no. 5, pp. 158-166, Oct. 2014

[8] ARC program at Auburn University: https://rfid.auburn.edu/arc/

[9] Monza R6 IC https://www.impinj.com/platform/endpoints/monza-r6/

[10] D. D. Deavours, "Analysis and design of wideband passive UHF RFID tags using a circuit model," IEEE RFID 2009, Orlando, FL

[11] M. Reich, C. Bauer-Reich, "UHF RFID impedance matching: when is a T-match not a T-match?", IEEE RFID 2014, Orlando, FL

[12] Voyantic https://voyantic.com/

[13] CST https://www.3ds.com/

[14] P. Nikitin, K. V. S. Rao and S. Lam, "UHF RFID tag characterization: overview and state-of-the-art", AMTA 2012, Seattle, WA