SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 8, No. 1, February 2011, 1-7

UDK: 621.396.029:537.531

Electromagnetic Modelling of UHF RFID Tags*

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Abstract: Paper presents a method for analysis of UHF RFID tags. After a brief overview of RFID system and UHF tags an electromagnetic (EM) simulation of tags in WIPL-D software was conducted. Electrical matching was performed after which tags were excited by a uniform EM wave, induced powers were measured and tag characteristics were compared.

Keywords: RFID, UHF, Tag, Modelling, Impedance matching.

1 Introduction

RFID (Radio Frequency IDentification) are systems for wireless identification of objects [1]. Rather than identifying objects themselves (which would require complex sensors on board of the identifying machine) tags are being placed on objects and from that point on they will uniquely identify those objects. The presence of a tag, which is more easily identifiable in an RFID system, is now equivalent to the presence of the object. A simplified system model is given on Fig. 1 and consists of the following:

- software - keeps the database of identified objects
- reader – antenna which will read the tags
- multitude of tags for object marking

According to a designated protocol for communication between the system and tags the reader will sequentially query the tags in its surrounding and determine if they are present or not and then send this information to centralized software. Thus, the system will have an up-to-date database of present objects which is refreshed in real-time.

In a typical RFID system there will be a lot of tags so their design is rather simple (dictated by cost) and often excluding an integrated battery which would allow them to act as an independent transmitter. Instead, communication between a reader and a tag is usually performed using the principle of modulated back-scattering [2]. This technique is well known from radar theory

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*Award for the best paper presented in Section *Antennas and Propagation*, at Conference ETRAN 2010, June 7-11, Donji Milanovac, Serbia.

where an incident wave from radar would reflect from the target and be received by the radar now with changed parameters. Change in the wave amplitude depends on the target's physical properties (size and material). In the example where tag is being irradiated by the field of the reader it has been shown that the intensity of the reflected wave would be dependent strictly on the match of the antenna to the tag's chip. We will use this phenomenon to transmit data from chip to reader. When reader queries the tag, tag will the input impedance of its chip (thus changing the match of the chip to the antenna) according to the information stored in the memory. For instance bit 1 could be transmit by having very high impedance seen in the chip and 0 by having very low. Bit by sequence of bits entire content of the memory could be transmit to the reader which could then continue its communication protocol with other tags.

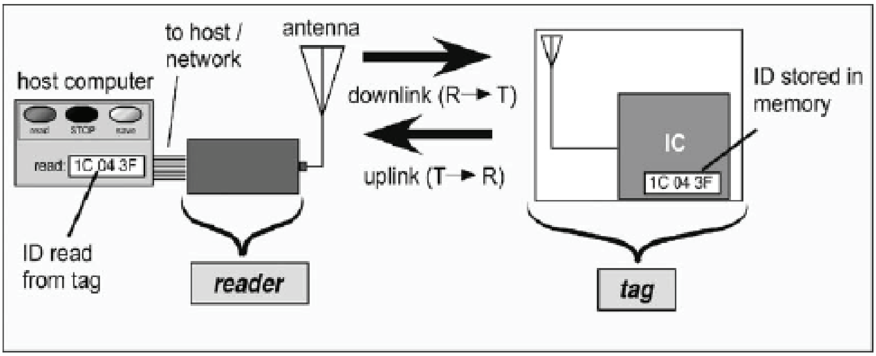

Fig. 1 – *System model* [1].

Tags are electronic structures which are consisted of an IC (Integrated Circuit) containing the object's ID and an antenna which tag uses to communicate with reader. There are many properties a tag can have (frequency, power, dimensions to name a few). According to frequency allocated to these systems tags will work in the following frequency ranges:

- LF (100 kHz);
- HF (13.56 MHz);
- UHF (900 MHz, and 2.45 GHz).

Some of the concepts we will deal with in this paper are:

- Match between the antenna and chip (we will not consider modulated back-scatter but rather try to determine which antenna is best matched to it's respective chip);
- Activation energy (alternatively power), or the minimum level of electrical field necessary to activate the tag;
- Dimensions of tags, which are an important parameter for the manufacturers.

Further on we will present the analysis method which we have used to simulate the behavior of EM UHF tags working in UHF band using WIPL-D (software based on Method of Moments).

2 Tag Models

In order to simulate a simple RFID system we should have an operating reader which will excite the tags. This reader should be similar to the ones used in real systems. Since complete data sheets with this kind information were not available to us we have decided to energize the tags using uniform EM waves. This wave would have a unit amplitude ($E = 1$ V/m) and corresponding polarization (since tags are planar structures it was easy determining the axes of polarization). We have found several tags from the manufacturers (and here we thank them for the samples they provided us with) whose dimensions we took and then created their models in WIPL-D. Antennas were modelled by thin plates of conductivity 14 MS/m^2. Chips have been modelled by concentrated loadings, where Z_{chip} was chosen to be $Z^{*}_{antenna}$ since we wanted to have the maximal transfer of energy. We did not model smooth bendings as they are found on the tags (see Fig. 3.) as this would complexify the analysis without any significant change in the result. We did not model the effect of tag substrate (the chip and antenna are to be found in the air dielectric), neither did we use a complicated model for the base of the chip – connection between antenna and chip is modelled by a thin wire.

Table 1 contains the parameters of the tags, such that have been found in data sheets used by the manufacturers.[2] We have found tags of two different manufacturers, two tag per each and chip information could be extracted [3-7]:

- Alien: 9554 (C_{input}=1.2pF) and 9640 (C_{input}=0.85 pF)
- UPM: models Belt and Web (C_{input}=0.9 pF)

After creating the tag models antenna impedance was checked in the program. This impedance was later compared to that specified by the manufacturer and the results are to be found in the **Table 1**. Simulated UPM tags show a good match to data provided by data sheet. 9640 shows a certain deviation from the expected value whereas the reactance of 9554 is significantly different from the one provided by the data sheet. We were not able to answer why this is the case.

The paradigm by which tag manufacturers work is the creation of an optimal antenna for a given chip they have decided to use. We have used

[2]Pay attention that these analyses have been conducted in 2009 so some of the information regarding the tags might be out-dated. In any case, the point of this paper is not to compare individual tags but rather to give a methodology of analysis.

reverse engineering and we wanted to see what are the properties of the antennas they made. By checking the reactances of all the antennas we were able to conclude that they were all positive. This goes in hand with the fact that matching is performed between antenna and chip. Namely, in order to do impedance matching (required for maximum transfer of power) reactances should be of close absolute values and different signs. Since chips are of negative reactance [2] antennas should be of positive reactance and this is why they are ususally constructed in form of dipoles.

Table 1
Electric parameters and tag dimensions.

	ALN 9554	**ALN 9640**	**UPM Belt**	**UPM Web**
R_{tag} [Ω]	16.86	19.4	13.51	5.079
X_{tag} [Ω]	236.9	175.1	196	195.4
X_{chip} [Ω]	–145	-205	–194	–194
S [mm^2]	2618	804.96	1126.54	1581

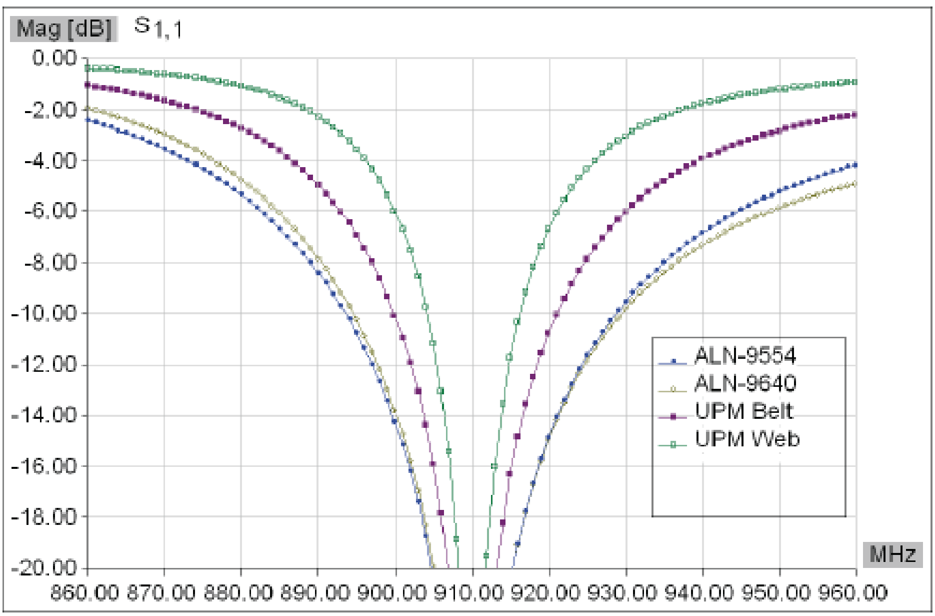

Fig. 2 – *Tag match in the UHF RFID frequency range.*

Fig. 3 – *Analyzed tags with their respective models in* WIPL-D.

3 Simulation Results

We have already stated that we were not interested in modulated back-scatter tecnique but rather in impedance matching and power transfer. Also, we are very interested in the power read at chip ports caused by the presence of EM wave. Characteristics of wave correspond to a wave created by a linearly polarized reader with 50 Ω impedance and power 20 mW that is to be found at approximately 2 m from the tag. Theoretical expression for the electric field generated by such an antenna is given:

$$|E_\theta| = \left| \mathrm{j}\frac{1}{4\pi}\sqrt{\frac{\mu_0}{\varepsilon_0}}\underline{I}\,\beta d \sin\theta \frac{\mathrm{e}^{-\mathrm{j}\beta r}}{r} \right| = \frac{30U}{R}\frac{\pi}{3}.$$

Powers required for activation of these chips are [4-7]:

- –14 dBm for ALN 9554;
- –18 dBm for ALN 9640;
- –15 dBm for UPM tags.

Greatest absolute power level induced by the wave is found in the chip UPM Belt, whereas ALN 9640 seems like the best when compared to required power (energy) of activation – in the widest frequency band it is over the power of activation. This could be due to the better chip it is using (lower activation energy requirement). Smaller antennas generally show weaker performance than bigger antennas so for the same performance we could state that the smaller antenna is better. Using these criteria we could say that ALN 9640 is the best antenna in this test, but, as stated before this could be the consequence of a better chip being used.

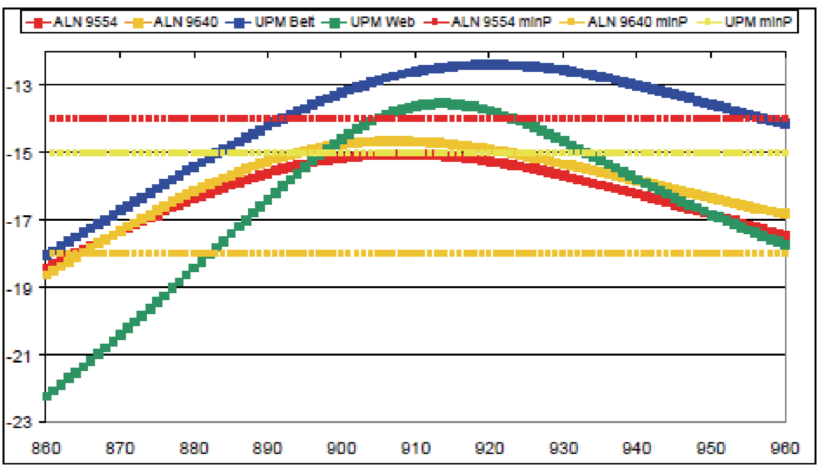

Fig. 4 – *Power simulated at chip ports with respective minimum activation powers.*

We should repeat that all analysis were conducted on an air substrate, which is a constricting simplification as these tags are intended to mark objects made from all sorts of materials. In most of the applications it is expected that they will be used on wooden material and cardboard boxes so the impact of material would not be great. But, there are applications (especially in pharmaceutical industry) where tags would be placed on objects containing high percentage of water, or even worse, on objects consisting of metal. In this case all the antenna properties will be worse and the impact of surface upon which the object is placed will need to be studied further. This had not been done during the course of this paper and is something that should be investigated in the future.

4 Conclusion

For this study EM tag models have been developped in WIPL-D and analysed. Tags were modelled as structures consisting of antenna (modelled with plate of conductivity 14 MS/m) and chip (concentrated loading). Antenna impedance have been determined and thus chip impedances have been accordingly attributed. Impedances for UPM chips show good match with data sheets whereas there is a certain difference for ALN 9640 and a noticeable difference for ALN 9554.

Created tags were excited with a uniform wave of unit amplitude (corresponding to a field generated by a standard reader at ~ 2 m). ALN 9640 has the required activaton energy in the entire frequency range whereas UPM Belt has the highest energy by absolute value. Clear advantage of ALN 9640 is that it is smaller.

In the future we should analyse the influence of different materials on antenna performance, as well as the effect of antenna substrate, since that neither had not been analysed.

5 References

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