On The Effect of Mutual Coupling on LF and UHF Tags Implemented in Dual Frequency RFID Applications

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Abstract - The interaction between passive Low Frequency (LF) and Ultra-High Frequency (UHF) tags in a dual frequency Radio Frequency Identification (RFID) tag is studied. This interaction is observed by building a dual frequency system from commercially available readers and experimentally determining the read range with the mutual coupling effects between the antennas. It is shown that by proper placement of the tags the individual performance of each tag can be preserved in the presence of mutual coupling.

Introduction

The deployment of Radio Frequency Identification (RFID) systems throughout the world has grown tremendously in recent years. This wide use of RFID systems is a result of significant research [1]-[4] and the reduction of system cost. In fact, a wide array of applications exist for Low Frequency (LF, 125.4-134 kHz), High Frequency (HF, 13.56 MHz) and Ultra-High Frequency (UHF, 902-928 MHz) RFID technologies. In particular, the use of RFID for animal identification is receiving considerable attention. Canada, Australia and many countries in Europe have mandated the used of electronic identification (EID) for various livestock species. Because of the wireless nature of RFID systems, antenna design is a major part of the design process. For example, antenna properties such as gain, efficiency and impedance are of great importance as well as knowledge of the complex radiation environment around the tag. Researchers have started to study the environmental effects on the tag detection [2]-[3] as well as many different dual-frequency applications [4]-[5]. But throughout this research very little data exists on how direct interaction (mutual coupling) of the RFID tags can effect tag detection. A first look at the proximity effects of other UHF tags on the tag detection has been performed [1] but a virtually unexplored interaction is the mutual coupling between LF and UHF tags in the newly emerging field of dual-frequency tags. A typical UHF tag that may be implemented in animal tracking is the Rampart line antenna [3] shown in Figure 1. This UHF tag is passive and is embedded in a weatherproof molding

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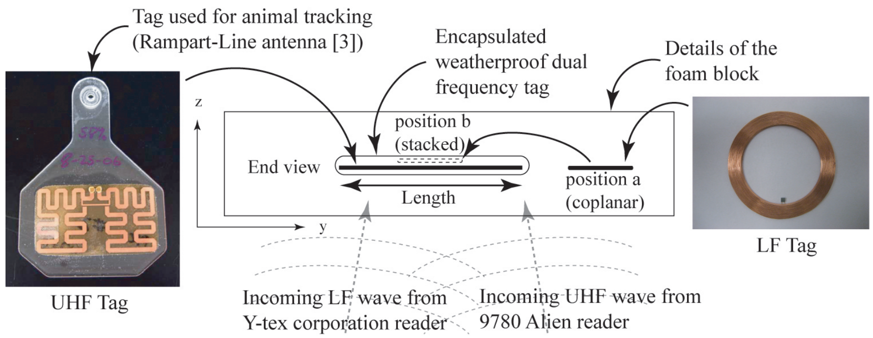

Figure 1: Foam block with an UHF Rampart line RFID tag embedded in a weatherproof molded eartag and a LF RFID tag.

that allows for easy attachment to livestock. In order to implement a dual frequency RFID tag a LF coil will also need to be embedded in the weatherproof molding and therefore is inherently in very close proximity of the UHF tag. Thus a very thorough understanding of the mutual coupling effects are of great interest and the impact should be understood for a successful design. The work presented here empirically studies the mutual coupling effect between the LF and UHF tags. To understand the mutual coupling impact on the tag performance the test setup shown in Figure 1 was built along with several dual frequency tags. A 9780 UHF Alien reader made by Alien Technologies [6] was used to detect the UHF tags and a Y-tex corporation LF reader was used to detect the LF tags.

Experiments

The first measurements taken with the setup in Figure 1 were with the LF reader trying to detect the LF coil in the presence of the UHF tag. A foam block was used to hold the UHF and LF tags. The UHF and LF tags were in two orientations relative to each other. The first is the coplanar orientation shown in Figure 1. This placed the UHF tag and the LF tag in the same plane. The second orientation was the stacked configuration shown in Figure 1. This placed the LF tag directly above the UHF tag. In both orientations the LF tag and the UHF tags are close enough to represent a placement of both tags in one enclosure or waterproof material. The plane including the UHF tag was changed from the xy-plane to the yz and xz planes to represent a reader interrogation from different directions. First, the maximum read range of the LF tag was determined without a UHF tag in close proximity. Then the Rampart line UHF tag was introduced and the orientation was changed to directly determine the effects the UHF tag had on the LF read range. The results from these measurements are shown in Table 1 in the form of percent change in read range of the LF tag. For the stacked configuration it is shown that the UHF tag had detrimental effects on the LF tag but the coplanar cases showed a 13.09 % improvement on the max read range. This is encouraging, because this illustrates to the designer that an effective LF design with a UHF tag in very close proximity can be achieved. The next tests included measurements with the 9780 UHF Alien reader trying to detect the UHF tags in the presence of the LF tags. The test setup for these results is shown in [3] and consists of a nonconducting structure that moves

Table 1: LF tag read range impact with Rampart UHF tag present.

Plane	coplanar	stacked
xy	-1.24 %	-3.00 %
yz	+13.09 %	-5.07 %
xz	0.00 %	-5.77 %

Table 2: Rampart tag read range impact with LF tag present.

LF coord.	z=0in	z=-3in	z=-7in
(0,0)	11.73%	-1.00%	-1.02%

Table 3: M-tag read range impact with LF tag present.

LF coord.	z=0in	z=-1in	z=-2in
(0,0)	-67.27%	3.17%	5.39%
(0,.5)	14.26%	3.17%	2.06%
(0,1)	-1.27%	2.06%	3.17%
(0,2)	-.44%	2.06%	4.56%
(0,3)	2.89%	1.51%	4.28%
(1,0)	-2.1%	1.51%	3.17%
(-1,0)	-2.56%	3.45%	-.9%

Table 4: Squiggle tag read range impact with LF tag present.

LF coord.	z=0in	z=-1in	z=-2in
(0,0)	-10.88%	.68%	-1.02%
(0,.5)	-91.84%	-.68%	-1.02%
(0,1)	-67.35%	1.02%	-.68%
(0,2)	-66.67%	0%	-.68%
(0,3)	-.45%	-2.04%	0%
(1,0)	-2.38%	-.34%	-2.04%
(-1,0)	.68%	-.68%	-1.36%

the tag vertically above a ground mounted LF and UHF reader. For these tests the plane of the UHF tag was chosen to be parallel to the plane of the reader antennas (i.e., the xy-plane shown in Figure 1) and the LF coil was placed only in the stacked orientation shown in Figure 1. At this point, three different UHF tags were chosen to be used in these measurements. The first UHF tag was the Alien M-tag. The LF and UHF readers were turned on and set to automatically detect any LF and UHF tags, respectively, in the area. The results from these measurements are shown in Table 3 in the form of percent change in read range of the UHF tag. The LF coordinate is the *relative* position with respect to the *center* of the UHF tag. For example, the (0,0) line in Table 3 refers to the LF coil being placed directly on the UHF tag and centered from the edge of the tag. Similarly, (-1,0) placed the coil 1 inch from the center of the UHF tag in the -x-direction. Next, the M-tag was replaced by the Alien Squiggle tag and the measurements were repeated. The results are shown in Table 4. Finally, the Rampart line antenna shown in Figure 1 was placed in the UHF test setup. The results from this setup are shown in Table 2. Notice that when the LF tag was placed right on the surface of the encapsulated Rampart line UHF tag and centered about the IC a significant improvement of 11.73% in read range was observed. This is likely due to the added inductive coupling between the two tags, which essentially tuned the UHF antenna to more closely match the input impedance of the IC located on the tag. The negative performance of the M and Squiggle tags can be attributed to this same tuning effect.

Discussion and placement suggestions

The results from Tables 1-4 show that the interaction between the LF and UHF tags can have a significant impact on the individual LF and UHF tag performance.

This impact is especially apparent in the UHF test results. It is shown in Table 3 that if the LF tag was centered and placed directly on the surface of the M-tag the UHF read range was reduced by as much as 67.27%. Similarly, it is shown in Table 4 that if the LF tag was slightly off center and placed on the surface of the squiggle tag the UHF read range was reduced by 91.84%. Then, in both cases, by moving the LF tag to the edge of the UHF tag the UHF read range was only reduced by a few percent. But, by moving the LF tag to the edge of the UHF tag the footprint of the dual-frequency tag will be noticeably larger and will *not* fit in the weatherproof encapsulant in Figure 1. This larger footprint problem is overcome by the Rampart line. The Rampart line results presented in Table 2 illustrate that with proper antenna design the UHF and LF tags can be in very close proximity and perform as well as other dual-frequency configurations with a larger footprint.

Conclusion

The performance of many different dual frequency tag configurations were tested in a commercially available dual frequency RFID system. It has been shown that the interaction between the LF and UHF tags can have a significant impact (i.e., 91.84% reduction in read range) on the performance of each individual tag. But, in all cases it has been shown that by proper placement of the LF and UHF RFID tags the performance of each individual tag in the dual-frequency tag can be preserved. In the Rampart line case to preserve the performance of an individual tag a larger footprint was not needed.

References

[1] H.-J. Li, H.-H. Lin and H.-H. Wu, "Effect of antenna mutual coupling on the UHF passive RFID tag detection," *IEEE Antennas and Propagation Society International Symposium*, San Diego CA, USA, Jul. 5-11, 2008.

[2] X. Qing and Z.N. Chen, "Proximity effects of metallic environements on high frequency RFID reader antenna: Study and Applications," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 11, pp. 3105-3111, Nov. 2007.

[3] B.D. Braaten, G.J. Owen, D. Vaselaar, R.M. Nelson, C. Bauer-Reich, J. Glower, B. Morlock, M. Reich and A. Reinholz, "A Printed Rampart-line antenna with a dielectric superstrate for UHF RFID applications," *2008 IEEE International Conference on RFID,* The Venetian, Las Vegas, NV, Apr. 16-17, 2008.

[4] T. Deleruyelle, P. Pannier and S. Bourdel, "Multi-standard slot antenna in the 860-960 MHz and 2.45GHz RFID band," *IEEE Antennas and Propagation Society International Symposium*, San Diego CA, USA, Jul. 5-11, 2008.

[5] K.S. Leong, M.L. Ng and P.H. Cole, "Investigation on the deployment of HF and UHF RFID tag in livestock identification," *IEEE Antennas and Propagation Society International Symposium*, Honolulu HI, USA, Jun. 10-15, 2007.

[6] Alien Technology, *www.alientechnology.com*