RFID Tag Reading Effects of Cylindrical Conductive Packages

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***Abstract* — We study two classes of passive UHF RFID tag antennas: bowties and slots, on conductive cylinders. We find better performance can be achieved when the tag is cross-polarized with the main axis of cylindrical containers. The performance degradation under co-polarization can be attributed to the reduction of radiation efficiency and the detuning of antenna impedance due to the stronger scattering interference from the metallic package. Our results serve as a general guideline to determine the right tag orientation for reliable readability.**

***Index Terms* — Radio frequency identification (RFID), antennas, tags, transponders.**

I. Introduction

RFID has been studied for more than five decades if we regard the paper published by Harry Stockman [1] as the birth of the idea of modern passive RFID technology. However, the idea of using backscattering power for communications was not a reality until recent years when cheap integrated circuit processes and sensitive RF front-end circuits became readily available. Traditional RFID systems working in the HF and LF bands have limited range due to their near-field communication constraint. Backscattering RFID systems in the UHF band, on the other hand, having the capability to achieve longer range, greater data rate and faster read speed, have rapidly attracted end users attention in the applications of supply chain, transportation, etc. [2]

The passive UHF RFID system, however, suffers from material effect when a tag is applied close to liquid and metal content [3]. The liquid absorbs energy from the reader and less energy can be converted to energize the tag. Liquid and metal also detune the tag antenna such that the original design impedance is shifted and radiation pattern is distorted. For tagging metallic objects, several papers dealt with the issue by proposing different antenna designs. For example, [4] investigated an electromagnetic band gap structure and [5] proposed an inverted-F antenna to avoid performance degeneration. In this paper, we study the metallic effect on RFID performance by exploring the cross-polarization and co-polarization radar cross section (RCS) responses from the package, and the scattering field interaction of the package with the tag.

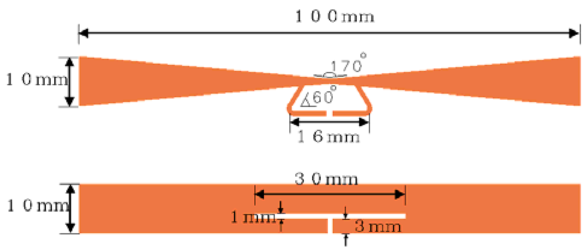

Fig. 1. Antenna dimension : bowtie antenna (top) slot antenna (bottom).

II. Antenna design and Analysis

The tag chip we use for this study is the EPC Gen-1 Class-1 chip. The chip comes with a bonding strap, so we can apply conductive epoxy to attach it to our own antennas. Because the chip input terminals are a balanced structure, we use an Agilent N5230A 4-port network analyzer to directly measure the differential input impedance of the chip without a balun. The chip input impedance is a strong function of the driving power because both the junction resistance and capacitance of the rectifying diode in the chip depend on the forward current. In order to characterize the chip impedance properly, we measured the chip at 915MHz and swept the power from -30dBm to 10dBm. We found that when the driving power was below -10dBm, the chip input impedance was fairly constant and close to 12-135j ohms. Our antennas were designed to match this impedance.

The general design considerations for RFID tag antennas have been discussed in [6]. Tag antennas in most cases are constrained to a small dimension and printed dipole or slot antennas on flexible substrate are common choices. However, high radiation efficiency cannot be easily achieved [7] in a small form factor. Some complex meandering techniques have been proposed for printed dipole antennas to enhance the radiation efficiency and achieve good matching [8]. In this paper, we present a simple and yet compact bowtie antenna design which can achieve good impedance matching as well as high radiation efficiency in UHF band. We also design a magnetic field sensitive slot antenna, so we can compare the performance of two different classes of antennas in our experiment. Both antennas have compact dimensions

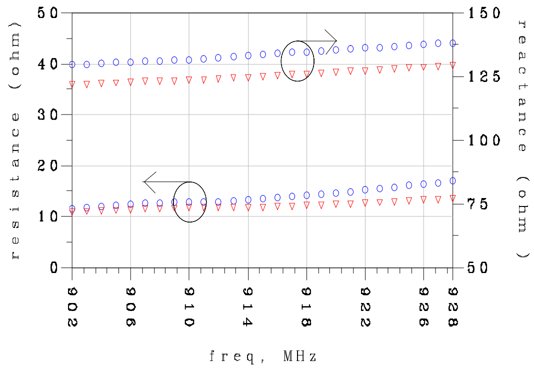

Fig. 2. Measured antenna impedance : blue circle – bowtie, red triangle - slot

Fig. 3. The package with a tag placed horizontally.

of 10mm x 100mm, which can fit into most standard RFID labels. They were fabricated on FR4 substrate with thickness of 0.8mm.

The antennas were designed using 3D FEM simulator, HFSS. The small loop in the center of the bowtie antenna is used to adjust the input reactance, while the flare angle of the bowtie can be used to control the radiation efficiency. For the slot antenna, the dimension and position of the slot in the center of the antenna were adjusted for the same purpose. The final antenna designs are shown in Fig. 1. In addition to the same dimensions, the two antennas are designed such that they have similar impedance and radiation characteristics. The impedance of both antennas is shown in Fig. 2. Both are linearly polarized and have omnidirectional radiation pattern in the H-plane with peak gain of 1.9dBi and 1.6dBi for the bowtie and the slot, respectively.

III. EXPERIMENT

The package considered in this paper is a carton of metallic cans as shown in Fig. 3. Each carton has a 3x2 array of cans. Each can measures 155mm in diameter and 160mm in height. It is a good candidate for our experiment because 1) it represents a very popular package for consumer goods; 2) it has air space between each can so that the tag antenna is not totally detuned and still can be read at a considerable range.

In the experiment, we have used an anechoic chamber and a conveyor system to measure the static and dynamic performance of the tags, respectively. The polarization of the package is verified by measuring its RCS with a dual polarized antenna.

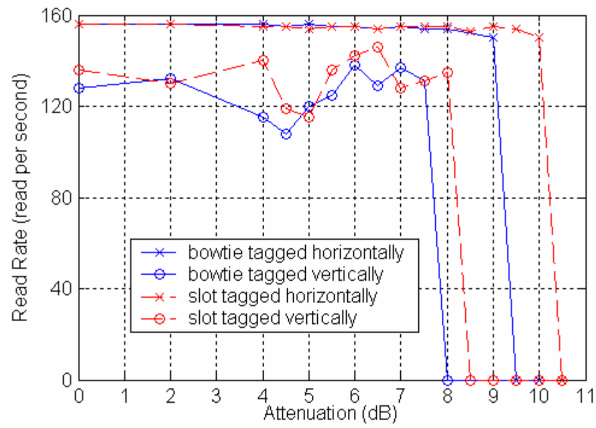

Fig. 4. Measured read rate from the tagged package in the anechoic chamber.

A. Static experiment in anechoic chamber

We used an Alien ALR-9932 EPC class-1 reader and a circularly polarized antenna to read the tags in an anechoic chamber. The maximum read rate this reader can achieve is about 160 reads per second (rps). We set the distance between the reader and the tag, d = 1m and the height of the tag from the floor of the chamber to 1.2m. A tunable attenuator with a minimum step of 0.5dB was used to determine the maximum attenuation when the reader could not read the tag. This attenuation value L_a corresponds to the minimum transmitter power P_{min} required to activate the tag at distance of d. In this paper, we measure only L_a as a metric of the tag performance because the theoretical maximum range R of the tag when the transmitter EIRP equals to 36dBm can be derived based on the Friis transmission formula as:

$$R = d \cdot 2^{\frac{L_a + L_c}{6}} \qquad (1)$$

where L_a is in dB and L_c is cable loss in dB.

The tags were first measured without the package at horizontal and vertical orientations. Both tags had consistent read rate (>135 rps) in each orientation until the maximum 9dB attenuation was reached and the read rate dropped to zero. This shows that the two tags have similar performance in free space. We then measured the tagged package, and the read rate of two orientations is shown in Fig. 4. We call the horizontal position cross-polarization and vertical position as co-polarization because the package is vertically polarized

TABLE I
DYNAMIC PERFORMANCE OF THE TAGS

Speed of Conveyor	Low – 150 (ft/min)				High – 300 (ft/min)			
Antenna type	Bowtie		Slot		Bowtie		Slot	
Orientation	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Read Rate (rps)	336	172	232	158	252	96	202	81

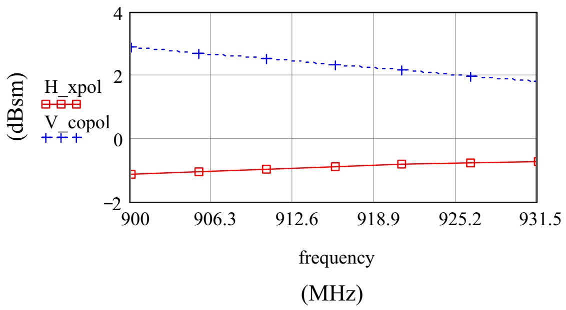

Fig. 5. Measured RCS of the package.

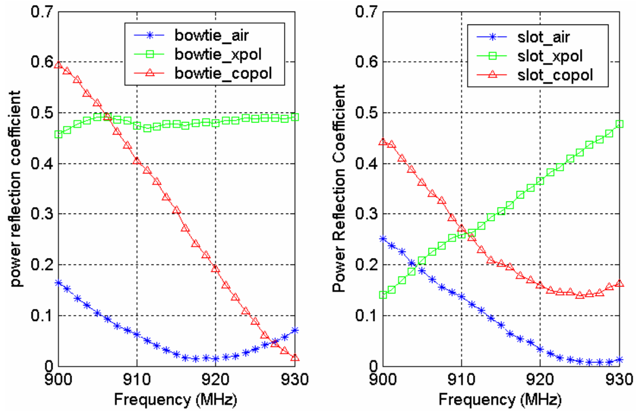

Fig. 6. Power reflection coefficient of antennas in the air and with the package.

from the measured RCS data. Fig. 5 shows the vertical RCS of the package is about 2.5dB to 4dB larger than its horizontal RCS in the UHF ISM band.

B. Dynamic experiment on conveyor belt

In real applications, tagged objects are usually being read at a given speed, such as on a sorting conveyor or on a forklift passing a receiving portal. The read duration will be reduced when the tag is moving at high speed and it may affect RFID reliability. We measured the dynamic performance of the tags using Alien ALR-9780 reader which can achieve higher maximum read rate up to 400 reads per second. The speed of the conveyor belt was set at 150 and 300 feet per minute. One circularly polarized antenna was connected to the reader and six of each type of the tags were attached to the package boxes on the same spot as in the static experiment. The measured read rate of two orientations is shown in Table I.

IV. DISCUSSION

From the static read rate measurement in Fig. 4, the tag performs better when it is placed horizontally than it is placed vertically. The performance improvement is 1.5dB and 2dB, which corresponds to about 19% and 26% improvement for bowtie and slot antennas, respectively. The performance change is due to the effect of the package on the antenna, so we investigate the possible antenna detuning effects by examining the radiation properties and impedance of the antenna with the package.

From Table II, the radiation efficiency is somewhat enhanced by the package when tag position is cross-polarized. On the other hand, the radiation efficiency decreases about 30% when the tag is co-polarized with the package. Impedance detuning by the package is also observed. We

TABLE II
RADIATION EFFICIENCY COMPARISON

Radiation Efficiency	Bowtie		Slot	
Orientation	H	V	H	V
Antenna Alone	93%	93%	91%	91%
Antenna with Package	96%	66%	94%	61%

TABLE III
ANTENNA GAIN COMPARISON

Peak Gain	Bowtie	Slot
H – cross-polarization	3.4dB	3.4dB
V – co-polarization	2.6dB	2.4dB

measured the impedance of the antennas with the package and calculated the power reflection coefficient as

$$\gamma = \left| \frac{Z_a - Z_c^*}{Z_a + Z_c} \right|^2 \qquad (2)$$

where Z_a is the antenna impedance, Z_c is the chip impedance, and Z_c^* is complex conjugate of Z_c. From Fig. 6, we notice a more significant impedance detuning effect on the bowtie antenna than on the slot antenna because the bowtie antenna is an electric field sensitive antenna and the image current induced on the package tends to detune the antenna impedance more than the magnetic slot antenna. In terms of static performance, we have observed that the slot antenna is better than the bowtie antenna for tagging metallic packages.

We also observe that the antenna gain of both tags under two orientations is enhanced, as shown in Table III. However, the gain increase of cross-polarization is about 1dB higher than that of co-polarization. It shows the package is a good reflector to improve the radiation gain of the tags, especially when the tag is cross-polarized with the package.

The measured data on the conveyor belt confirms the effect of polarization of the package. The tag performs more consistently in a horizontal orientation than in a vertical orientation in terms of the read rate, even though all the six tags can be read for both orientations.

V. Conclusion

We have investigated the metallic package effect on the performance of a UHF passive RFID system. We use a common consumer product package and two typical classes of RFID tags to prove that when the tag is oriented such that it is cross-polarized with the package, it will perform better than when it is co-polarized. We have supportive results from the static measurement in an anechoic chamber and dynamic measurement on a conveyor system. We also analyze the degradation of antenna performance from the perspective of radiation efficiency, antenna gain, impedance and the package RCS response. We have seen more adverse effects on the antenna performance when the tag is co-polarized with the package. This result can be used as a general guideline for RFID end-users to properly place the tag on metallic products.

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