Analysis of Bow Tie Array RFID Tag Antenna for Paper Reel Identification Systems

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Introduction

Nowadays the applications of passive ultra-high frequency (UHF) radio frequency identification (RFID) systems are increasing rapidly [1]. One of the most challenging applications for passive UHF RFID systems is identification of industrial paper reels [2]. In paper industry there is a need for an automated identification system that would carry on the identification code of a specified reel throughout its life cycle. Nowadays when barcode identification systems are used in paper reel identification, the identification code disappears when the wrapping paper and the barcode are removed. On the contrary, the radio frequency identification (RFID) tag would be attached on the core of the reel and thereby the reel would be identifiable throughout its life cycle as long as the reel is in use. Since the tag will be attached on the core of the reel the tag has to be read through paper which attenuates the electromagnetic wave. As a dielectric material, paper also affects the electrical dimensions of the tag antenna design [2]. Typically, the dielectric constant (ε_r) of paper varies from 2 – 4 [3] based on the paper quality and environmental conditions.

Promising results of using broadband bow tie tag antennas in paper reel identification have been achieved recently [4]. However, a single bow tie tag antenna does not have sufficient read range performance when read through the paper layer of an industrial paper reel [2]. Therefore, in this paper a bow tie array-type configuration is proposed to improve the performance. The validity of the bow tie array is demonstrated by HFSS simulations, return loss (S11) measurements and practical read range measurements. The array results are compared with a single bow tie tag antenna.

Antenna Designs

The geometry and dimensions of the single bow tie tag antenna are presented in Fig. 1. Its length, 98.5 mm, is approximated to be half-wavelength of 915 MHz electromagnetic wave inside paper layer with dielectric constant ε_r = 2.8. Figure 2 presents the proposed array construction. It consists of three bow tie elements which are connected to each other with strip lines.

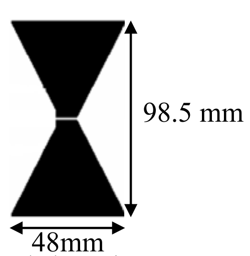


Fig. 1. Single bow tie tag antenna.

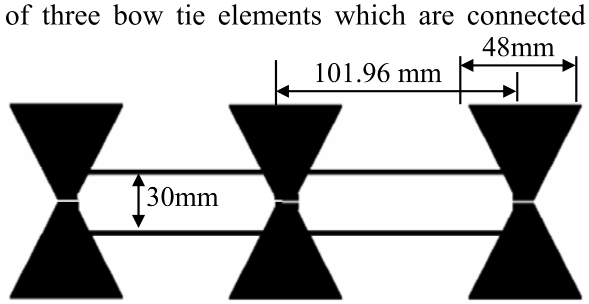


Fig. 2. Unfolded three-element bow tie array.

The microchip is connected to the middlemost bow tie element. The other two elements do not have microchips affixed to them. The three-element array will be bent around the paper reel core as presented in Fig. 3 after which the paper is winded around the core. The expected advantage of the array-type tag antenna is better omnidirectional backscattering performance in the *H*-plane especially in the directions opposite to the bow tie element with the microchip. The ability to read a vertically orientated paper reel omnidirectionally 360 degrees around it in the horizontal plane eliminates the need for knowing which side of the reel core the tag is attached to. The concept of omnidirectional reading is presented in Fig. 4. This is an important feature in paper industry applications [2].

Fig. 3. Three-element array mounted on a reel core.

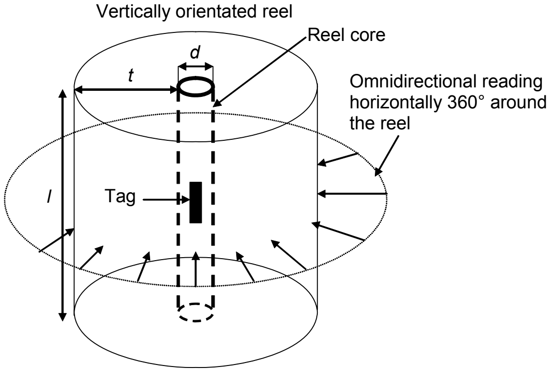
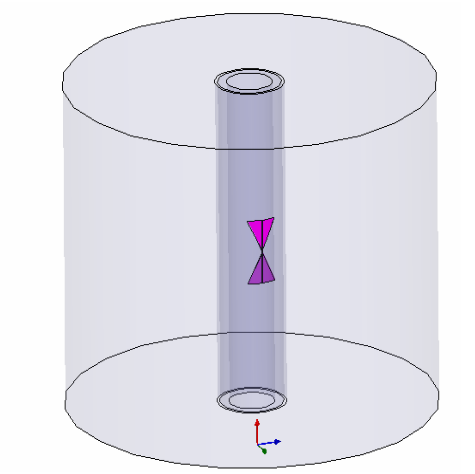


Fig. 4. The concept of omnidirectional reading.

The structures of both a single element and the array of three elements are modeled using HFSS as depicted in Fig. 5 and Fig. 6. A small air gap is kept between the paper frame and the paper layer in order to insert the antennas into it. The antennas are modeled with copper patches of 0.1 mm thickness. The simulated paper frame is assumed the relative permittivity of 4.



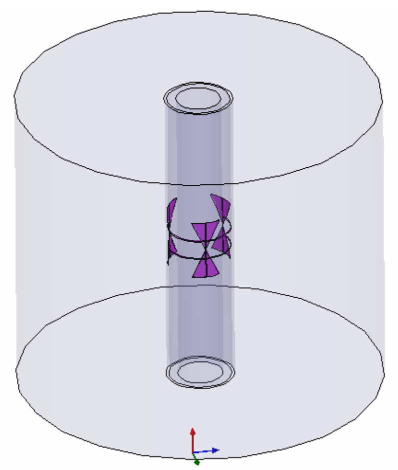


Fig.5. Single-element modeling with HFSS. **Fig.6.** Three-element array modeling with HFSS.

Return Loss Measurements

The effects of paper on the antenna design impedance matching were studied with input impedance measurements using a network analyzer. The target input impedance for the tag antenna design was 40 + j94 Ω [5]. First, the input impedance of the bow tie array was measured on the reel core with outer diameter of 105 mm without any paper. After that, 0.10 m, 0.20 m and 0.30 m thick layers of copy paper were gradually added on the antenna design. Using the measured input impedances, the reflection coefficient and return loss were then calculated. Figure 7 presents the results within 850 – 960 MHz bandwidth. The results show that the return loss around 915 MHz is sufficient with all the studied paper thicknesses. Generally, adding the paper on the antenna design improves impedance matching. However, there is some variation in the quality of impedance matching with different paper thicknesses.

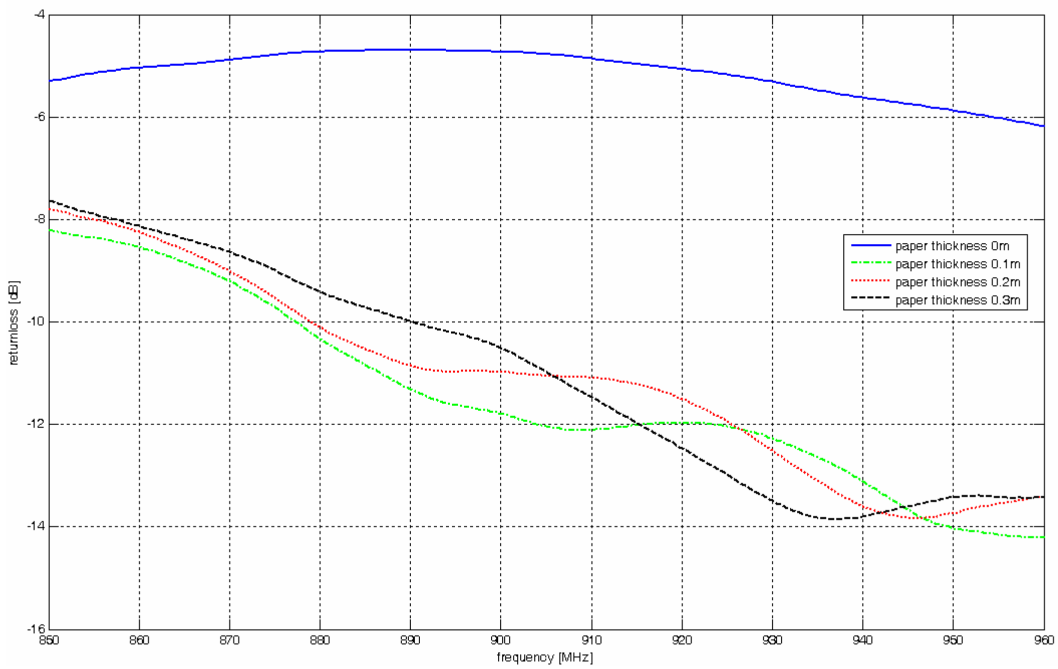


Fig. 7. Effects of paper on the return loss of the three-element array.

Practical Read Range Measurements

To study the read ranges of the bow tie array design and to compare its performance with a single bow tie tag antenna, practical read range measurements were carried out. The reader unit was Federal Communications Commission (FCC) compliant Gen 2 reader manufactured by Alien Technology. Reader antennas were linearly polarized. The tag antennas were placed on a reel core inside a laboratory testing paper reel with 740 mm diameter. The diameter of the testing reel was smaller than the diameter of industrial paper reels. Typically, an industrial paper reel has 1200 mm – 1500 mm diameter. However, laboratory testing gives reliable guidelines of the tag antenna performance and is helpful in comparing the simulated and measured results.

Figure 8 presents the measured read ranges. Letter **S** indicates the direction of the element with the microchip. The read ranges are measured from the center of the reel and the presented read ranges thereby include the reel radius (0.37 m) and the distance in free air from the paper layer surface. The read ranges of the single bow tie were generally longer than the read ranges of the array. However, the direction directly opposite to **S** gives an exception: the read range of the array from that direction is 0.56 m longer than the read range of the single bow tie. This indicates that the bow tie array can harvest energy to the microchip and backscatter the identification data back to the reader more efficiently from the backside of the reel. The previous studies have shown that a single bow tie antenna cannot be identified from the opposite direction to **S** when placed inside an industrial paper reel [2]. The read range increase achieved with the proposed array structure will thereby be an advancement.

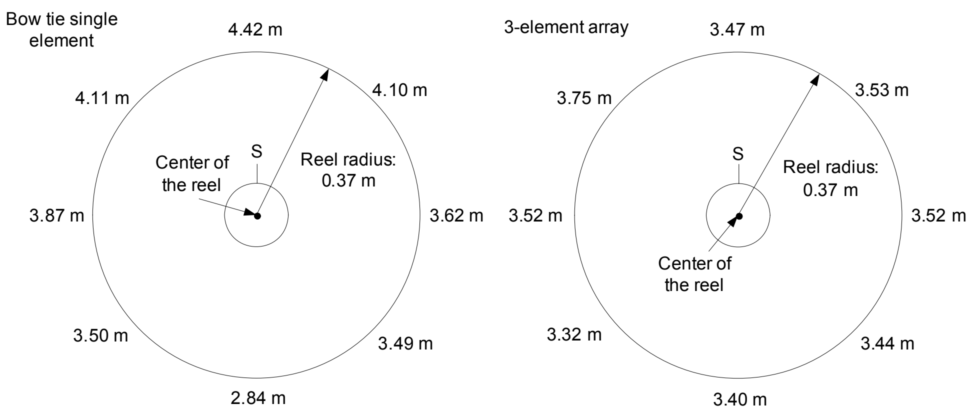


Figure 8. *Practical read ranges of the antenna designs.*

Conclusions

This paper presents an analysis and measurement results of using bow tie array-type tag antenna design in paper reel identification. The advantage of the bow tie array compared to a single bow tie is better readability from the opposite direction to **S**. This indicates that the bow tie array can harvest energy to the microchip and backscatter the identification data to the reader more efficiently from the backside of the reel. Future work includes read range testing using industrial paper reels to confirm the omnidirectional performance. To improve the radiation patterns and to further increase the read ranges, optimization of the array feed lines and the impedance matching to the microchip will be carried out.

References:

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