A Wideband UHF RFID Reader Antenna Array with Bow-tie Elements

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***Abstract*— This paper presents the design procedure of a wideband UHF RFID reader antenna with polarization diversity suitable for searching tagged items. The antenna consists of a microstrip array with alternating orthogonal bow-tie elements, which are fed in series by a pair of microstrip lines. The elements are designed to provide the required bandwidth. The inter-element distance is adjusted to be about 0.8λ at the center frequency, whereas the elements provide in-phase excitation and create two orthogonal electric field components that give beams with polarization diversity. Simulated results indicate that the bandwidth covers the frequency bands of ETSI and FCC (865-928 MHz) standards. Regarding the coverage, it was deduced that the antenna can identify tagged items in a semi-cylindrical volume around its axis. The radius of coverage depends on the input power and tag sensitivity. A case study of reading tagged items in front of a cabinet with shelves is presented.**

***Index Terms*—*RFID*, reader antenna, bow-tie elements.**

I. Introduction

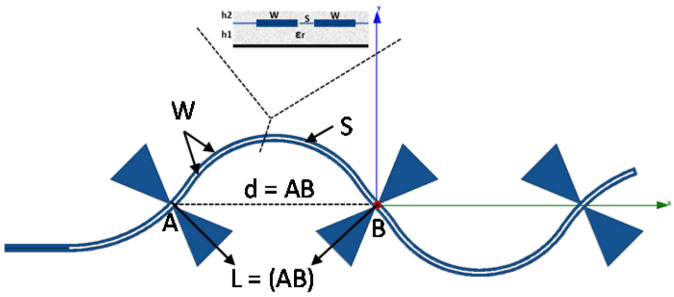
Radio Frequency Identification (RFID) is a technology with a plethora of applications in primary sectors of the economy. These include healthcare and pharmaceutical industry, transportation, libraries, warehouses, logistics, manufacturing, retail, energy and tracking [1, 2]. It is well known that low cost in combination with labor reduction and productivity improvement led the industry to the development of the RFID technology, [3].

In this work, the design of a UHF RFID reader antenna that operates in the frequency band of 865 to 928 MHz is presented. The antenna is intended to be used for searching of existing, misplaced or lost tagged items in various environments (libraries, hospitals, warehouses, etc). An array of mutually orthogonal elements, which are fed in series by a microstrip line, constitutes the antenna of the reader. In the design given in [4], pairs of dipoles were used as array elements. In the present work, the pairs of dipoles are replaced by bow-tie elements, which improve the bandwidth and the gain of the antenna. The bow-tie elements excitation produces two orthogonal electric-field components. As a result, it is expected to have polarization matching with the tags irrespective of tag orientation. Fig. 1 presents an RFID antenna that covers shelves loaded with goods. The antenna array is mounted vertically to the shelves and is connected to the corresponding input port of the reader.

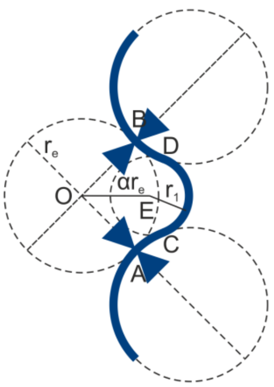
Fig. 1. A UHF RFID reader antenna for searching tagged items.

A schematic diagram of a mutually orthogonal bow-tie antenna array is shown in Fig. 2(a). The bow-tie elements are excited by a meander-shaped microstrip line with an appropriate length to achieve the phase adjustment, [5]. Fig 2(b) depicts the proposed meander-shaped geometry and the position of the two bow-tie elements.

A series of simulations was performed using commercial EM software (ANSYS High Frequency Structure Simulator - HFSS) in order to optimize the radiation characteristics of the antenna.



(a)



(b)

Fig. 2. (a) A meander-shaped microstrip line to excite mutually orthogonal bow-tie elements and (b) The proposed meander-shaped geometry of the antenna.

II. Antenna Array Design

The need for an adjustable phase difference, which differs from the corresponding inter-element one, leads to the use of meander-shaped type lines. By choosing the proper length of the meander-shaped line, [4], we can achieve the desired phase difference between the elements for a specific inter-element distance. From Fig. 2(b), it is found that, for a given distance *(AB)* between the two elements, the corresponding arc length [*AB*] of the meander-shaped line is given by:

$$[AB] = \sqrt{2}(AB)\left[\varphi + \left(\frac{2}{\sin\varphi + \cos\varphi} - 1\right)\left(\varphi + \pi/4\right)\right], \qquad (1)$$

$$OE = 2\frac{\sin\varphi}{(\sin\varphi + \cos\varphi)}(AB) \qquad (2)$$

The meander length [*AB*] can be adjusted by using the appropriate value of φ.

The desired bandwidth and coverage were both met, upon completion of a parametric study of the bow-tie element and the antenna array geometry. The connection of the N bow-tie elements to the feeder line is equivalent to the parallel connection of two N terminals – pair circuits. Following the equivalent circuit analysis, the antenna input impedance and the excitation current of each one of the bow-tie elements can be found.

The first step of the design procedure is the optimization of the bow-tie element geometry (see Fig. 3(a)), in order to cover the desired bandwidth. The second step includes the derivation of the elements number and its mutual distance. The designed wideband antenna array is mounted on a substrate and a superstrate layer (see Fig. 3(b)) of polystyrene foam with a relative permittivity of 2.5 and a dielectric loss tangent equal to 0.029. The dimensions (length × width) of the foam are 800 mm × 200 mm, and the corresponding thickness is 28 mm for the substrate and 14 mm for the superstrate. A copper foil with $\sigma = 58 \cdot 10^6\ S/m$, acting as a reflector of the array antenna, is placed under the substrate. Fig. 3(b) depicts the proposed antenna array model.

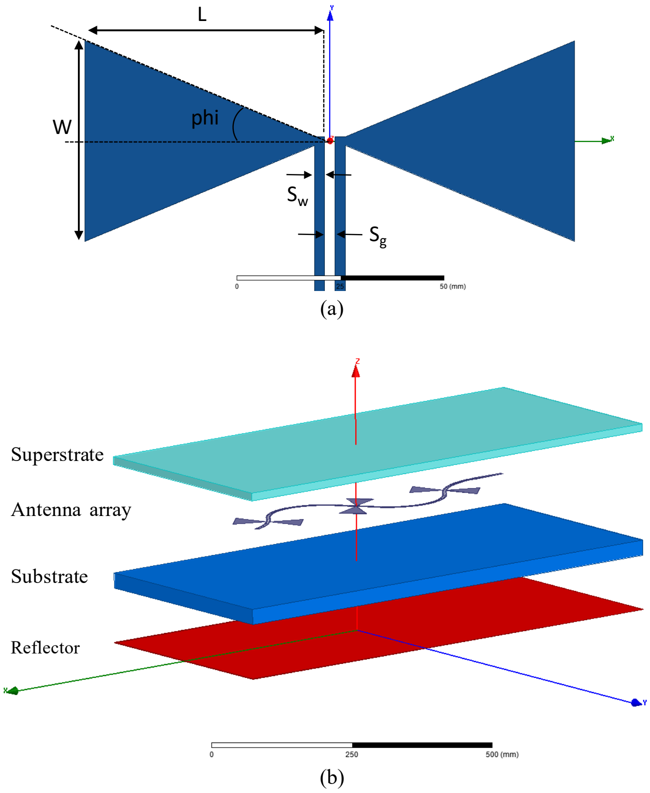
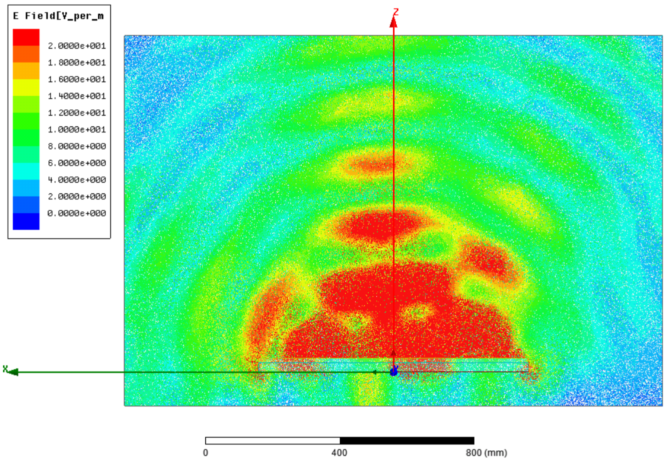
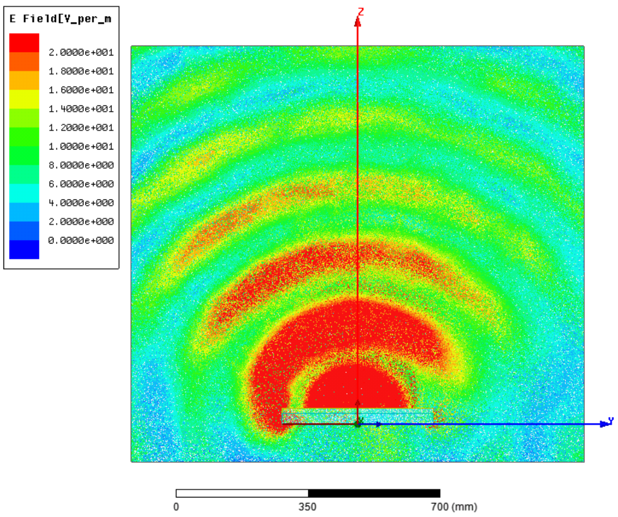


Fig. 3. (a) The optimized bow-tie element (L = 58.5 mm, W = 48.74 mm, phi = 22.6 deg, Sw = Sg = 2.5 mm); (b) The proposed antenna model (angled and expanded view).

Fig. 4 shows the electric field distribution (total radiated electric field in V/m) of the final geometry of the wideband antenna at 867 MHz. The input power is set equal to 30 dBm. It is observed that a semi-cylindrical volume that extends to a radius of more than 60 cm is sufficiently covered. The tag readability threshold was chosen at 5 V/m.



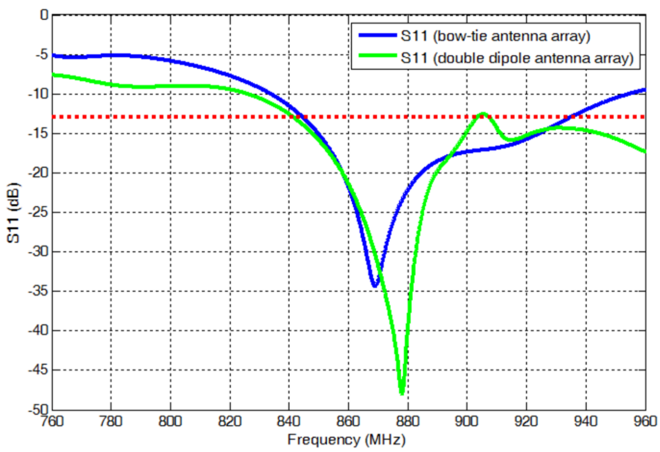
(a) XZ plane – Y = 0.0 mm



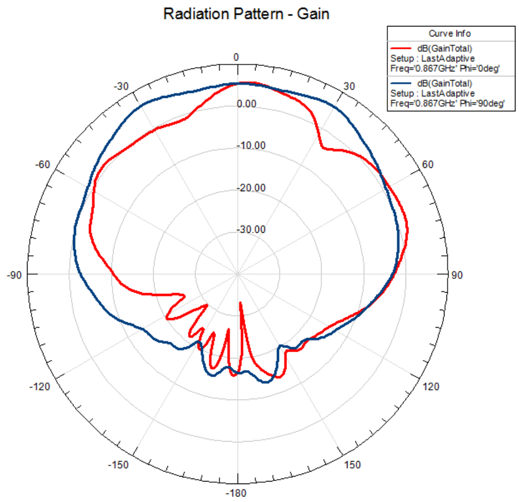
(b) YZ plane – X = 0.0 mm

Fig. 4. Electric field distribution (total radiated electric field in V/m) of the reader antenna array with N = 3 bow-tie elements (d = 0.8λ at 867 MHz) and an input power of 30 dBm at 867 MHz (simulated results): (a) Vertical plane; (b) Horizontal plane. Electric field values that are larger than 20 V/m are not distinguished in color scale.

Fig. 5(a) depicts the simulated return loss (S11) of the designed wideband bow-tie antenna array as a function of frequency, in contrast to the return loss of the corresponding double-dipole antenna array. From the comparative results it is evident that the operating bandwidth (RL>13 dB) of the bow-tie antenna array is 89.6 MHz and covers a wide frequency range (845.1 - 934.7 MHz), whereas the bandwidth of the double-dipole antenna array is 61.3 MHz (842.2 - 903.5 MHz). Moreover, the radiation pattern (gain) of the antenna array in horizontal and vertical plane is given in Fig. 5(b). As a conclusion, the return loss of the designed antenna meets the desired requirements and covers both the ETSI and the FCC frequency bands.



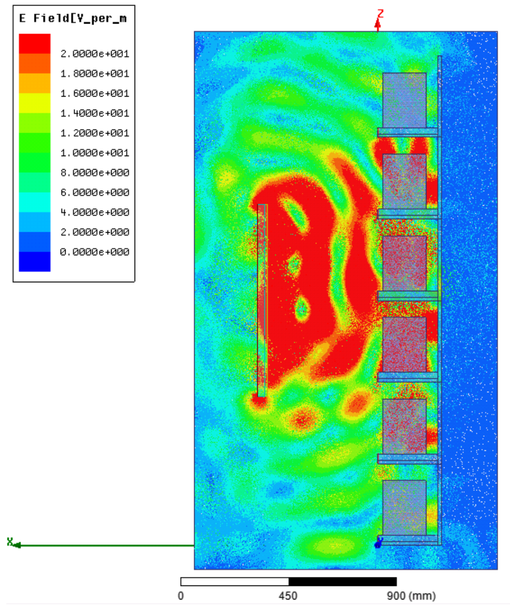
(a)



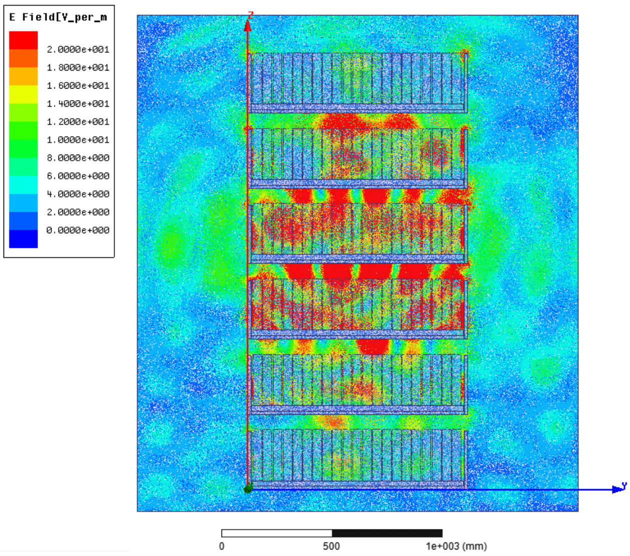
(b)

Fig. 5. (a) Comparative results of the simulated return loss (S11) versus frequency of the designed bow-tie wideband antenna array in contrast to the return loss of the double-dipole antenna array (red dot line: -13 dB reference level); (b) The radiation pattern (gain) of the designed bow-tie antenna array in vertical and horizontal plane at the frequency of 867 MHz.

The designed antenna array is positioned in front of a metallic library cabinet with six shelves loaded with several tagged books (case study). Fig. 6 illustrates the field coverage in the vicinity of the UHF RFID antenna at 867 MHz. The relative permittivity of the books is set equal to 3. The distance between the reader antenna and the library cabinet is set to 50 cm (typical value). As shown in Fig. 6, the radiated electric field coverage in the entire library cabinet model is quite satisfactory. If we choose a tag readability threshold of 5 V/m, we can easily obtain that any tagged book placed on the library shelves will be identified. In the case study presented, polarization diversity in tags with the worst power sensitivity (>-8 dBm) is assumed.



(a) XZ plane



(b) YZ plane

Fig. 6. The field coverage (simulated results) of the reader antenna in front of a metallic library cabinet (input power = 30dBm, tag threshold 5 V/m, (a) XZ plane – Y = 498 mm (center of the antenna)); (b) YZ plane – X = 0 mm (center of the antenna)).

III. Conclusion

This paper demonstrated a UHF RFID antenna for applications in the frequency bands of ETSI and FCC standards. The proposed antenna consists of a microstrip array with three geometrically alternating orthogonal bow-tie elements, which are fed in series and in phase by a meander shaped microstrip line. The operating bandwidth (RL>13 dB) of the bow-tie antenna array is 89.6 MHz (46% wider compared to the operating bandwidth of the double-dipole antenna array) and covers both the frequency bands of ETSI and FCC standards. Simulated results have shown that any tagged item within a semi-cylindrical volume of a 600 mm radius in front of the RFID antenna can be identified regardless of its tag orientation.

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