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All-in-One UHF RFID Tag Antenna for Retail Garments Using Nonuniform Meandered Lines

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Abstract—An all-in-one UHF RFID tag antenna using nonuniform meandered lines for retail garments in the textile industry is presented. The all-in-one antenna offers relatively low cost, wide band, compactness, and good conjugate matching in the presence of its robust housing with good dipole-like read range. Results show an antenna with a wide bandwidth of 900 MHz and a long read range of 10.2 m making the UHF RFID tag antenna using nonuniform meandered lines a potential candidate for retail garments in the textile industry. Simulations are corroborated by measurements and are in fair agreement.

1. INTRODUCTION

In recent years, Radio-Frequency Identification (RFID) systems operating at Ultra-High Frequency (UHF) have been significantly adopted for identification and tracking in applications such as human monitoring, health-care, library and inventory management, and Internet of Things (IoT) [1, 2]. For UHF RFID systems, various frequency bands have been assigned worldwide, i.e., 866–869 MHz for Europe, 865–868 MHz for New Zealand and India, 908.5–914 MHz for Korea, 902–928 MHz for USA, and 940–943 MHz for China [3]. Typically, an RFID system consists of a reader and a tag made of a chip and an antenna. The tag chip is powered through the antenna by signals originating from the reader and sends back the information using the back-scattering principle [4, 5]. Therefore, a good tag antenna design is crucial to compactness, captures more radiation, and achieves a good impedance match with the chip. Moreover, particularly for inventory management applications, the tag antenna design should also consider the effect of its enclosure encompassing strong magnetic locks attached to cloths as the only means to provide security against its removal to avoid theft. An Acoustic Magnetic System (AMS) technology which is additionally used for security needs to coexist within the housing of the RFID tag for cost effective tagging solutions [6, 7].

In the literature, various techniques have been reported to achieve the aforementioned specifications. For instance, the inductive coupling technique improves impedance matching of a tag antenna; however, it compromises radiation efficiency [8]. Similarly, the T-matching technique [2, 9] achieves broadband matching, reduced size, and improved efficiency, but the designs [10, 11] do not consider the effect of magnetic locks on the cloth tags. In contrast, cloth tag [12] has wider bandwidth and is designed with a magnetic lock and housing made of Acrylonitrile Butadiene Styrene (ABS) material, but is not with AMS technology.

In this paper, to comply with the specifications detailed in Section 1, an all-in-one UHF RFID tag antenna using nonuniform meandered lines for retail garments in the textile industry is presented. The all-in-one antenna offers relatively low cost, wide band, compactness, and good conjugate matching in the presence of its robust housing with good read range. The remaining of the paper is organized as follows. Section 2 shows the proposed UHF RFID tag antenna. Section 3 provides the analysis and results and Section 4 the concluding remarks.

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2. PROPOSED UHF RFID TAG ANTENNA

The UHF RFID tag antenna using nonuniform meandered lines is edged on a single-sided PCB of an FR4 substrate having $\epsilon_r = 4.4$, $\tan\delta = 0.02$, and thickness 1.54 mm with copper deposition of 20 microns. FR4 is attractive due to its relatively low cost. The geometry of the proposed tag antenna is shown in Fig. 1(a) and shows the presence of the AMS, ABS casing, and magnetic lock, as shown in Fig. 1(b). A meander-line technique [13–15] is used to increase the electrical length of the antenna, and nonuniform lines (track width, w', and length, l') with smooth corners form the grounds of this newly proposed design. The optimized w' and l' were found iteratively. The tag antenna was matched with an EPC global Class-1 2nd generation Higgs-4 chip [16] having input impedance $21.55 - j191.45\,\Omega$ at 866 MHz and capable of operation in the frequency range 830–960 MHz. Therefore, the input impedance of the antenna was conjugately matched with the tag chip impedance, and the matching loop of the proposed design was conveniently tailored. The tag antenna was simulated using commercial electromagnetic software Ansys HFSS. The parameters of the resulting design are listed in Table 1 with values of w' and l' shown in Fig. 1(a). Table 1 shows the optimized parameters of the proposed tag. Because of the optimization, small variations in any of the parameters lead to impedance mismatch and therefore a constrained reading range. However, using them conveniently in a nonuniform meander line fashion influences the reading range and f and c the impedance matching positively.

Table 1. Design parameters of the proposed tag (dimension in mm).

a	b	c	d	e	f	g	h	i	j	k	l
16	4.3	33	13	3.2	1	2.8	1.7	0.5	1.2	0.7	3

The performance of the proposed tag antenna is evaluated next.

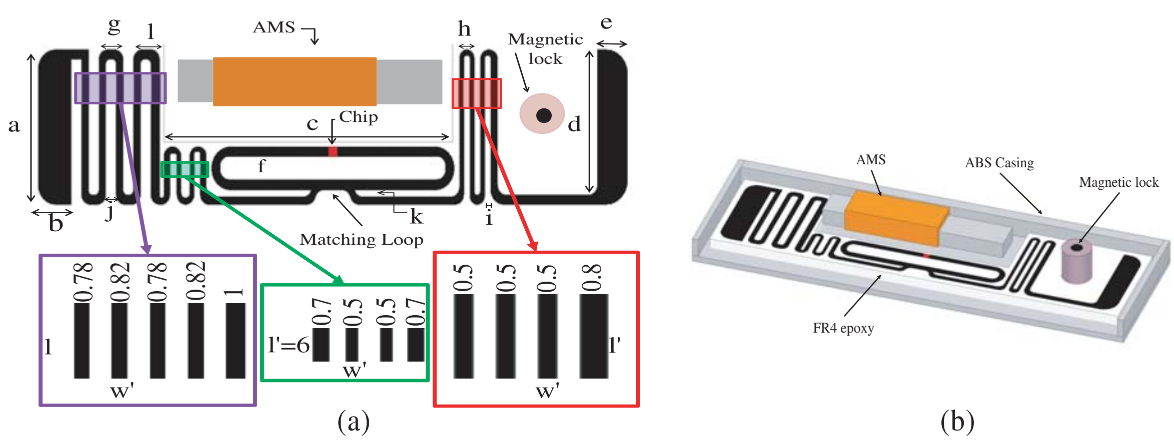


Figure 1. The proposed UHF RFID tag antenna (a) with nonuniform meandered lines, (b) simulated prototype in Ansys HFSS.

3. ANALYSIS AND RESULTS

Initially, the antenna's power reflection coefficient (PRC) was simulated and compared to the same using uniform meandered lines instead. The uniformity was given by meandered lines whose tracks $w'_1 - w'_{13}$ (Fig. 1) are all 0.5 mm width. The result is shown in Fig. 2. A bandwidth (BW) of 900 MHz (measured at -10 dB) covers all the worldwide UHF RFID allocated bands introduced in Section 1. The proposed tag has a bandwidth (BW) of 830 MHz–960 MHz measured at -10 dB, and the RFID chip resonance is within the lower and upper frequencies of the BW at 866 MHz. To corroborate that this is

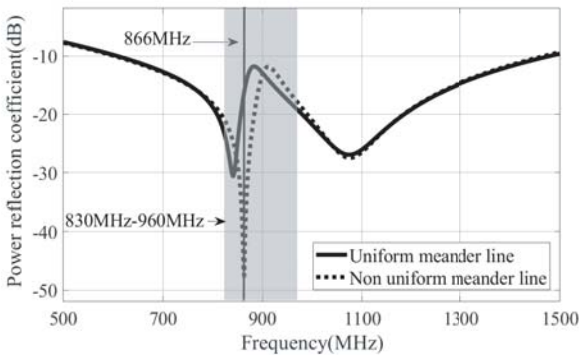


Figure 2. Simulated power reflection coefficient of the proposed antenna.

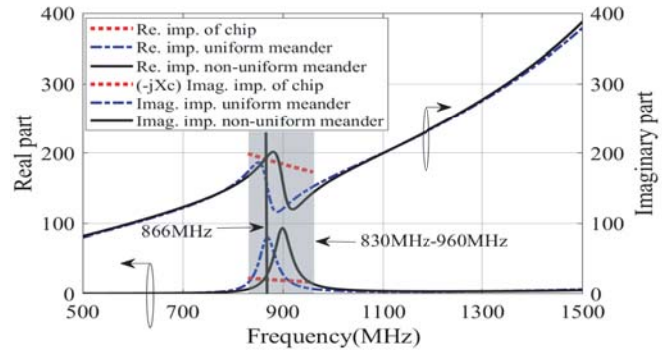


Figure 3. Impedance response of the antenna and the chip against frequency.

true, the impedance vs. frequency is plotted and compared to the tag's chip impedance in Fig. 3. The response using uniform meandered lines is also shown for comparison. Corresponding results showed good conjugate matching between the antenna using nonuniform meandered lines and the chip. The simulated and measured sensitivity read patterns of the tag antenna measured at 866 MHz are shown in Fig. 4. The measurement setup is described later in the manuscript. Dipole-like radiation pattern is observed with omnidirectionality in $\phi = 0°$ plane. The simulated gain, corroborated by measurements, of the antenna without the chip was 1.2 dBi; this is for reference purposes. With the chip this was 11.48 m sensitivity read range. Similarly, 1.2 dBi was also achieved by the antenna using uniform meandered lines; however, the nonuniform achieved better conjugate matching (Fig. 3). The simulated magnetic and current distributions of the proposed antenna at 866 MHz are shown in Fig. 5. The highest magnetic and current density near the matching loop is observed. Therefore, it is reasonable to predict the minimal impact in the performance of the antenna due to alterations at its end edges where density is low. To corroborate this, a parametric study was done by trimming the radiator's end edges, b and d elements (Fig. 1). This is presented in Table 2. Results corroborate the claim and show a fine tuning capability of the input impedance of the proposed tag antenna, specifically for the first 3–5 trims, with potential to size reduction (compactness).

Table 2. Parametric study of the proposed tag antenna's elements, b and d.

	element b			element d		
Trimming (mm)	Impedance ($R_a + jX_a$)	BW (MHz)	Read range (m)	Impedance ($R_a + jX_a$)	BW (MHz)	Read range (m)
0.0	$35.19 + j191.12$	900	11.48	$35.19 + j191.12$	900	11.48
0.5	$27.77 + j191.87$	900	11.48	$37.85 + j196.48$	890	11.40
1.0	$25.97 + j194.94$	900	11.38	$21.00 + j189.43$	895	11.47
1.5	$21.81 + j192.25$	888	11.48	$17.62 + j187.50$	886	11.40
2.0	$17.58 + j189.69$	885	11.44	$16.87 + j185.71$	880	11.14
2.5	$14.29 + j186.54$	890	11.19	$14.19 + j185.66$	880	10.45
3.0	$12.68 + j184.40$	888	10.79	$10.89 + j181.02$	887	09.71
3.5	$10.12 + j182.49$	887	10.24	$03.38 + j171.64$	890	05.73
4.0	$9.15 + j181.39$	885	09.70	$02.90 + j171.14$	895	04.80
4.5	$6.43 + j177.86$	888	08.34	$02.82 + j169.67$	880	04.70

The fabricated prototype and proposed tag with casing are shown in Fig. 6. The magnetic lock and AMS are fixed in a casing made of ABS material (from Wavelinx Ltd) to be accounted for. The

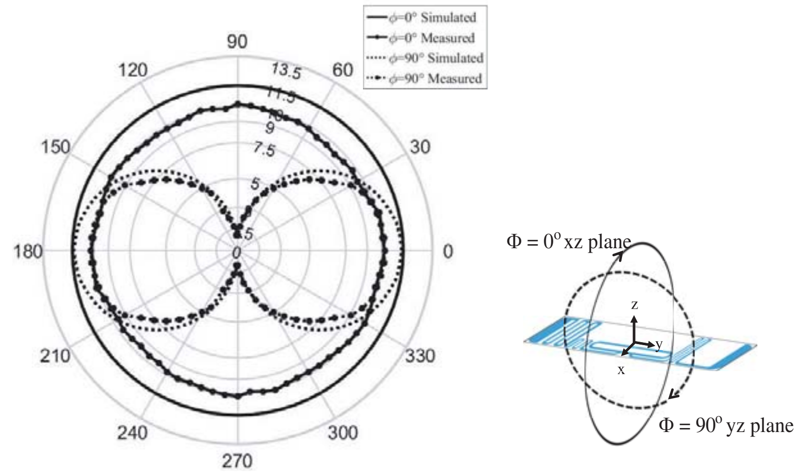


Figure 4. Simulated and measured sensitivity read range (m) patterns of the proposed tag antenna.

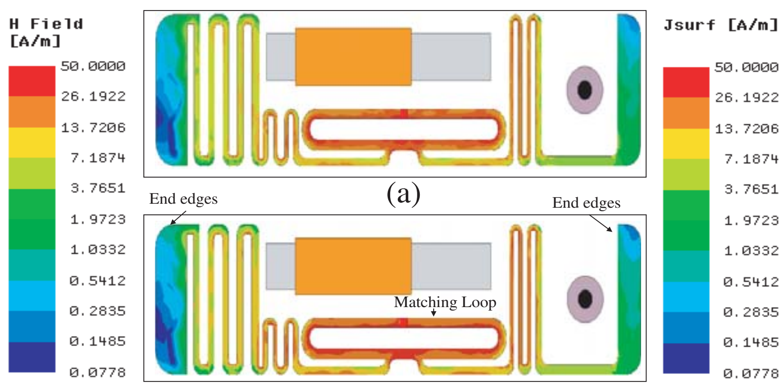
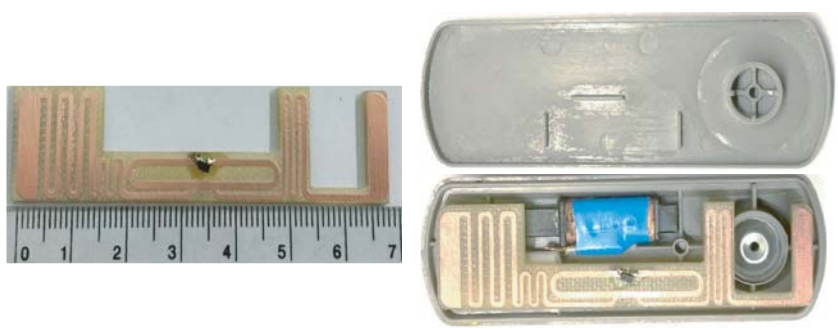


Figure 5. Simulated magnetic (a) current (b) distributions of the proposed antenna at 866 MHz.



(a) (b)

Figure 6. (a) Fabricated prototype (b) the proposed tag with casing.

following setup, shown in Fig. 7, which was used to measure the proposed RFID antenna configuration, is performed accordingly. Essentially, it uses a 6 dBi circularly polarized antenna connected to a Scratchnest RFID reader module [17] with maximum output power adjusted to 25 dBm and was tested for two different frequency bands of RFID: ETSI (865–868 MHz) and FCC (902–928 MHz) in a real indoor scenario. The tag attached to a cloth was initially placed at a far distance and moved slowly closer to the RFID reader until it was read; this found accurate sensitivity read-range of the proposed UHF

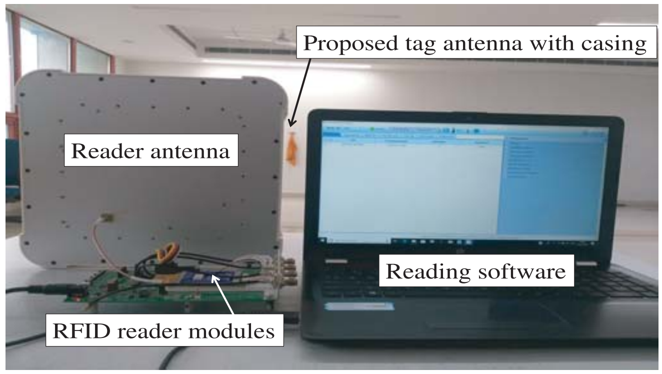


Figure 7. Measurement setup and configuration for the proposed RFID antenna.

RFID tag antenna for retail garments using nonuniform meandered lines.

To corroborate the measured results, the read range of the tag is calculated theoretically with Friss equation [18] $r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}}$ where λ is the wavelength, and $P_t = 25\,\text{dBm}$ and $G_t = 6\,\text{dBi}$ are power transmitted and gain of the reader antenna, respectively. G_r is the gain of tag antenna; $P_{th} = -20.5\,\text{dBm}$ is the chip sensitivity; and $\tau = \frac{4R_cR_a}{|Z_c+Z_a|^2}$, $0 \leq \tau \leq 1$, is the power transmission coefficient. $Z_c = R_c - jX_c$ and $Z_a = R_a + jX_a$ are the chip and antenna impedances, respectively. The theoretical reading range of the proposed tag is calculated as 11.48 m and ~ 9 m respectively for the 866 MHz and 915 MHz central frequencies.

In the measurements, different orientations of the tag showed insignificant read-range sensitivity variation in the $\phi = 0°$ plane due to the omnidirectionality of the tag antenna (Fig. 4). Therefore, for the boresight direction the maximum read-range was measured, and results were compared to theoretical ones in Table 3. Similarly, the tag antenna with uniform meandered lines was theoretically and experimentally measured and presented in Table 3 for comparison. The proposed nonuniform meander-line antenna shows higher 2.72 m (calculated) and 2.42 m (measured) sensitivity read range than its analogous design using uniform meander-line and fair agreement between the simulated and measured results. Compared to a commercially available uniform meandered line tag [12], the proposed antenna shows a 8.7 m improved reading range in the presence of the AMS. The deviation of ~ 1 m between results was due to the actual EIRP of the reader which was in practice slightly lower than the theoretical 31 dBm.

Table 3. Comparison of the measured vs. theoretical read range of the proposed tag antenna at 866 MHz.

	Read Range (m)	
	Calculated	Measured
Uniform meander-line	8.76	7.78
Proposed nonuniform meander-line	11.48	10.2

4. CONCLUSION

In this paper, an all-in-one UHF RFID tag antenna using nonuniform meandered lines for retail garments in the textile industry has been presented. The all-in-one antenna offers relatively low cost, wide band, compactness, and good conjugate matching in the presence of robust housing with good dipole-like read range. Results showed an antenna (in a casing made of ABS + AMS + Magnetic lock) with a wide bandwidth of 900 MHz and a long read range of 10.2 m radius making the UHF RFID tag antenna using nonuniform meandered lines a potential candidate for retail garments in the textile industry.

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