Transformation of Barcode Into RFID Tag, Design, and Validation

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***Abstract*— This letter demonstrates the possibility of combining advantages of barcode and radio-frequency identification (RFID) technologies on the same smart label. In this letter, several UHF RFID tag designs based on barcodes of different standards and sizes are realized and measured using a professional RFID measurement system. Measurements of all realized prototypes are in good agreement with simulations. Interesting results are obtained with a maximum RFID read range reaching around 12 m while keeping the prototypes readability as a standard barcode. Another tag configuration which avoids soldering the IC to the structure and based on the coupling of a near-field RFID tag to the barcode is also presented, showing a read range of more than 7 m.**

***Index Terms*— Antenna design, barcode, smart labels, UHF radio-frequency identification (RFID).**

I. Introduction

NOWADAYS, optical barcodes are very popular and commercially successful to identify items and automate checkout systems. Despite their limitations in terms of reading distance and identification by family, not per item, they are almost universal. Barcodes which represent data by varying the width and the spacing of some parallel lines are used in many other applications as automatic identification and data capture. However, radio-frequency identification (RFID) technology overcomes today the barcode limitations and also allows more effective and smarter applications. Therefore, RFID is now considered as a very popular wireless technique for tracking objects with a very effective traceability system for logistics and inventory applications [1].

Hybrid systems combining the advantages of both the barcode and RFID technologies can be accurately adapted to meet the specific requirements of many applications. It is worth noting that recently there are many projects to install hybrid track and trace system based on both the barcode and RFID technologies for identifying passengers' luggage in international airports worldwide [2]. Moreover, hybrid traceability solutions are being deployed in a variety of healthcare applications, including producing hospital wristbands and labeling for pharmaceutical unit-dose medications [3]. This letter aims to have a single tag design combining both technologies on the same smart label with a simple and reduced cost fabrication.

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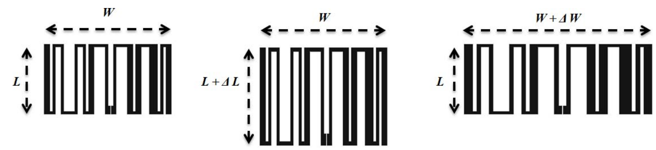

Fig. 1. Impedance matching based on the optimization of barcode dimensions: bar length (L) and bar width (W).

II. Barcode as Meander Antenna

The majority of RFID tag antenna designs is based on uniform or nonuniform meander line structures [4]. In order to achieve an acceptable read range, a good impedance matching between the meander antenna and the chip is required. The impedance matching is usually optimized with electromagnetic simulation tools.

A traditional barcode is composed of several parallel bars with varied widths and gaps. A small modification of a barcode can transform it to an RFID tag antenna just by connecting its vertical bars with very thin horizontal stubs. By connecting the bars to each other's, the barcode readability would not be modified. However, in order to have a good RFID read range, impedance matching with the RFID chip and antenna directivity should be optimized.

Impedance matching can be achieved by the optimization of both bar lengths and widths as illustrated in Fig. 1. While changing the barcode length does not affect its optical readability, the optimization of bar width should be realized carefully or elsewise the barcode cannot be scanned correctly. The optimization of bar width can be achieved merely by scaling the entire structure in the direction of the width axis, and thus the width of all bars and gaps is scaled with the same factor, and the optical readability is maintained.

Matching the IC impedance to the antenna is not the only parameter for designing RFID tags. Previous work [5] managed to match a quick response code to RFID chip. However, the overall radiation efficiency and directivity of the structure were very low which decreased the read distance to the range of dozens of centimeters.

Indeed, RFID tag read range is defined as the maximum distance at which the tag can be read. It depends on the chip sensitivity, tag antenna gain, polarization, and matching between the antenna and the chip. Using the Friis equation, it is possible to calculate the RFID tag's read range performance as

$$\text{Read Range} = \frac{\lambda}{4\pi}\sqrt{\frac{P_{\text{eirp}} G_{\text{tag}}\, p(1-|S|^2)}{P_{\text{th}}}} \qquad (1)$$

where λ is the wavelength of the carrier emitted by the reader, P_{eirp} is the regulated equivalent isotropic radiated power,

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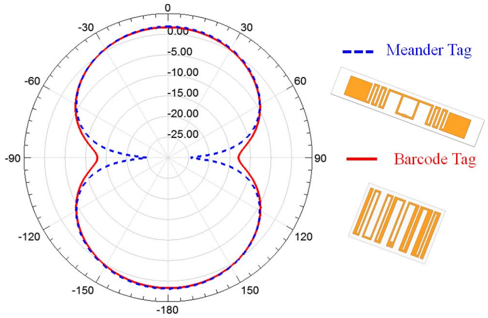


Fig. 2. Comparison between the simulated directivities of a conventional meander tag and the proposed barcode tag design.

P_{th} is the activation power of the chip, G_{tag} is the tag antenna gain, p is the polarization loss factor between reader and tag antennas, and $|S|^2$ is the power reflection coefficient given by

$$|S|^2 = \left|\frac{Z_{\text{chip}} - Z_{\text{ant}}^*}{Z_{\text{chip}} + Z_{\text{ant}}}\right|^2 \tag{2}$$

where Z_{ant} and Z_{chip} are, respectively, tag antenna and IC impedances.

Compared to conventional RFID tags, linear barcodes will have a similar omnidirectional radiation pattern as well as a good directivity. Fig. 2 shows a comparison between the simulated directivities of a meander tag and barcode tag of the same size using the 3-D full-wave electromagnetic simulation tool ANSYS HFSS. The meander antenna has a maximum directivity (at Phi 90°) of 1.98 dB, whereas the barcode tag has a lightly lower directivity of 1.82 dB.

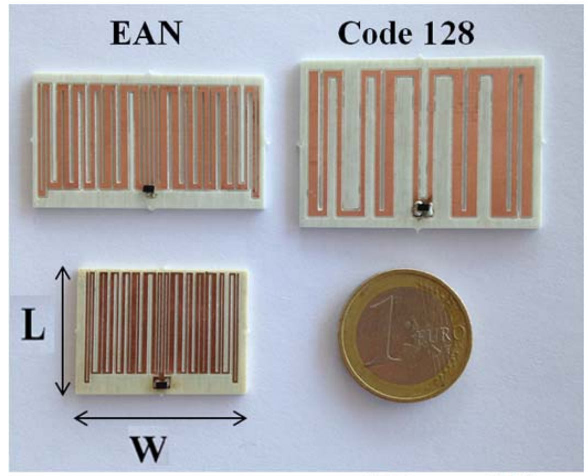
III. Simulated and Realized Monza-R6 Smart Labels

In this letter, EAN-13 and Code 128 barcodes have been considered to design smart labels as they are the most used barcode standards to label consumer goods as well as in logistics and transportation industries for ordering and distribution worldwide [6]. Barcodes were generated using Microsoft Office Barcode Add-In, where all barcodes are preconfigured according to industry standards. Barcodes are then exported under.dxf format for simulation and optimization with ANSYS HFSS. Analysis frequency band goes from 820 to 920 MHz, where reflection coefficient, gain, and read range are the main characteristics of interest.

Tags are optimized to match Monza-R6 RFID chip which is modeled as a parallel connection of resistance of 1.8 kΩ and capacitance of 1.37 pF. The RFID IC has a sensitivity of −20 dBm (10 μW). Two tags with different sizes based on EAN-13 barcode and a tag based on Code 128 are designed without exceeding the limits of barcodes' standard sizes. They are fabricated on Rogers RO4003 substrate of 1.52-mm thickness, as shown in Fig. 3. The dielectric constant and loss tangent of Rogers RO4003 are 3.55 and 0.0027, respectively, at the European UHF RFID operation frequency of 867 MHz.

IV. Measurement Results of Monza-R6 Smart Labels

All realized prototypes were successfully read using a handheld optical barcode reader. The UHF read range performance



Dimension (mm)	Code128	EAN (Large)	EAN (Small)
W	41	40	29
L	29	23	22

Fig. 3. Realized prototypes on Rogers RO4003 substrate. Code128 (right) and two different sizes of EAN (left).

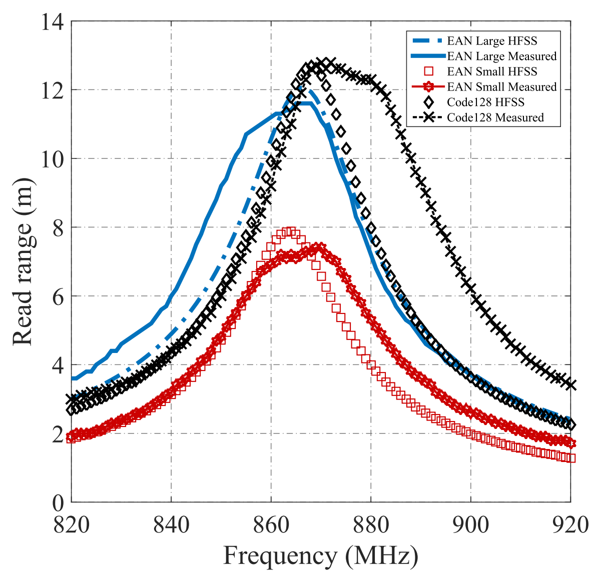
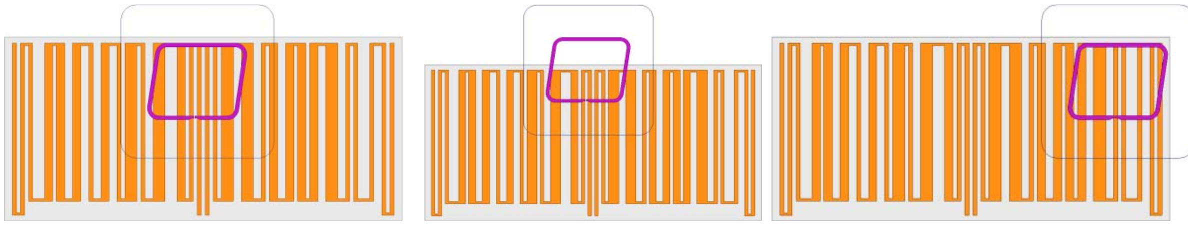


Fig. 4. Comparison between the read ranges of realized prototypes: HFSS simulations versus measurements.

of the realized tags was then measured using the Voyantic Tagformance measurement system. This system can provide the backscattered signal strength from the tag under test and thus estimates its read range. Fig. 4 presents a comparison between the measured and simulated read ranges for each of the three realized smart labels. A good agreement between measurements and HFSS simulations is achieved.

Code128 and EAN-13 (large) achieved a read range of 12.5 and 11 m, respectively. The small configuration design of EAN-13 achieved a lower performance of 8 m. This lack of performance is expected because a tag with smaller size presents a lower directivity reducing thus its read range.

These results demonstrate the feasibility of smart labels combing both the barcode and RFID technologies.



(a) (b) (c)

Fig. 5. Parametric study on the position of the AK tag. (a) Optimum performance as the AK tag is centered. (b) Weak coupling as the AK tag is shifted 5 mm away from the stubs. (c) Lower coupling as the AK tag is placed on the edge of the structure.

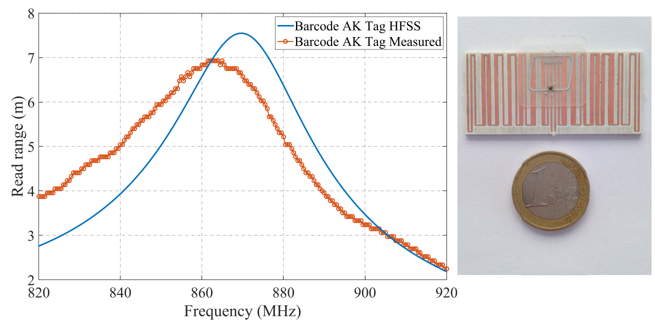


Fig. 6. Measured read range versus HFSS simulation of an AK tag coupled to EAN barcode at the optimum coupling position.

V. AK Tag Smart Labels

In Section IV, the Monza-R6 chip was soldered on the three presented prototypes. In order to avoid the soldering step, the adaptive kernel (AK) tag can be considered. It consists of an RFID IC deployed in conjunction with a small loop antenna based on a parallelogram shape (dimensions $= 11.54$ mm $\times$ 9.2 mm). The AK tag principle is inspired from the famous T-match technique, where a simple loop compensates the capacitance of the RFID chip while the two branches of the dipole or meander line increase the radiation resistance [7]. The main advantage of this configuration is its quite easy realization as the AK tag is just coupled to the barcode without the need to solder the RFID chip, where the strength of the coupling is controlled by the distance between the loop and the radiating body [7].

A parametric study on the optimum coupling position of the AK tag has been achieved. Fig. 5 shows three different positions of coupling, where the optimum performance is realized when the AK tag is centered in a way that the upper branch of the AK tag and the stubs connecting the bars are very close or overlapped (position A). This is because, in a meander-line structure, the surface current responsible for radiation is the horizontal part of the meander lines as it cancels each other in the vertical direction. The directivity of the structure decreases as the AK tag is placed 5 mm away from the stubs as in position B. The tag directivity also decreased at the third position C as the AK tag is placed on the edge of the barcode instead of the center as in position A. Fig. 6 shows the read range of an AK tag coupled to EAN barcode at the optimum position. The measured read range shows a good agreement with the simulation, where the maximum read distance is around 7 m instead of 0.5 m for the AK tag simple configuration. This configuration has a smaller read range compared to the other tags of the same size ($\approx$12 cm^2) because of coupling which reduces the overall tag gain compared to direct soldering and also due to the chip (Monza 5) which has a lower sensitivity of -17.8 dBm compared to the Monza-R6 (-20 dBm) as shown in Table I.

TABLE I
Main Characteristics of the Realized Tags at 866 MHz

Tag	Reflection coefficient (dB)	Gain HFSS (dB)	Area (cm²)	Read range (m)	Chip sensitivity (dBm)
Code128	-10	0.346	11.9	12.5	-20
EAN (Large)	-9	-0.596	9.2	11	-20
EAN (Small)	-11	-3.58	6.4	7.5	-20
EAN AKTag	-12	-1.78	12.4	7	-17.8

VI. Conclusion

In many applications, combining RFID and barcode on the same label is of great interest. This letter presented a proof of concept for smart labels combining both technologies. Two different barcode standards were simulated and tested. The maximum read range achieved is 12.5 m for a 12-cm^2 tag, whereas the smaller configuration of 6.3 cm^2 presents a lower read range of 7.5 m. A novel smart label configuration based on electromagnetic coupling with AK tag is presented. Parametric study on the coupling position was realized, where the tag achieved a read range of 7 m at the optimum position.

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