Compact diversity antenna for UHF RFID readers

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A diversity antenna combining four inverted-F antennas (IFAs) is evaluated for UHF RF identification (RFID) readers. Polarisation and pattern diversities are obtained for a sequentially rotated configuration of the IFAs. Mutual coupling between ports is minimised by etching quarter-wavelength slots into the ground plane. The resulting envelope correlation coefficient is less than 0.003 in the working band. A switching diversity scheme is then applied to evaluate the tags readability in a lab environment. It is shown that the antenna diversity enhances the reading range compared to a circularly or a linearly polarised antenna of the same size.

Introduction: One of the major problems facing RFID systems today is to increase the tag identification rates when a large number of tags is present in a small enclosure. The main cause for missed tags is the coupling between adjacent tags. Tag coupling yields what is sometimes called 'masking', but the antenna community will rather visualise it like a pattern distortion and a voltage drop at the antenna input. Under these conditions, the voltage at the chip input remains below the threshold, the tag cannot modulate the backscattered signal and cannot be identified by the reader. In addition, RFID communications normally take place in multipath environments and could suffer from large signal fadings which also reduce the identification rate.

On the other hand, it is well known that multi-element antennas (MEAs) and diversity techniques overcome the multipath fading and signal depolarisation problems [1, 2]. RFID readers usually integrate two or four output channels to allow some antenna multiplexing, i.e. antenna diversity with a switched combining scheme. But most of the time, RFID system integrators use cumbersome commercially antennas and distribute them over a large area around the region to scan.

In this Letter, we propose a new reader antenna built around four sequentially rotated IFAs and a diversity scheme. The diversity antenna is characterised in terms of S-parameters, envelope correlation coefficient ρe, polarisation and radiation patterns in the European UHF RFID band (865MHz–868MHz). Tags readability is measured for 38 passive tags packed in a cardboard box, first with the diversity antenna, then with commercial circular and linear polarised antennas.

Antenna design: The layout of the proposed structure is depicted in Fig. 1 including the IFA elements, the ground plane and the reflector occupying a total volume of 30 × 30 × 5cm. All of them are made up of copper material. The IFAs are mounted on the ground plane with a 90° sequential rotation between them [3]. IFA ports are fed through four coaxial cables. A reflector is used to reduce the back radiation of the antenna and placed 2 cm below the ground plane. To isolate the IFA ports, $\lambda o/4$ slots ($\lambda o \sim 34.6$cm) are etched in the half-length of the ground plane [4]. Slots modify the current flow on the ground plane and confine it around the slots boundaries [5, 6]. The structure is simulated using the commercial electromagnetic solver High Frequency Structure Simulator (HFSS).

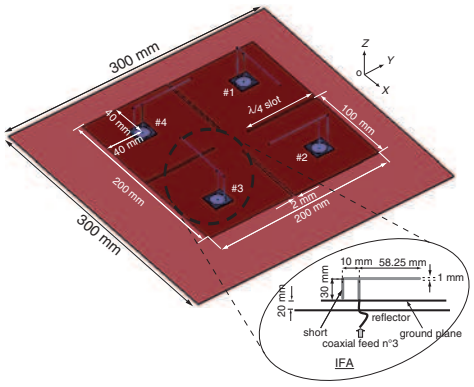

Fig. 1 *Top view of diversity antenna*

Antenna simulation and measurement: Simulated and measured S-parameters are plotted in Fig. 2, where IFAs are labelled as in Fig. 1. The reflection coefficients (Sii) are lower than −20 dB at the centre frequency 868 MHz with a 5.2% bandwidth (Sii ≥ − 8 dB without slots). Low mutual coupling between orthogonal (S12 < −12dB) and collinear (S13 < −20 dB) IFAs are obtained in the entire band with the slotted ground plane. The 40 MHz shift in the measured and simulated S13 could be attributed to the cable currents which are not modelled in the HFSS simulation. The fields radiated by these currents result in additional coupling between ports 1 and 3. Measured patterns of the antenna in Fig. 3 indicate a 5dBi IFA gain and a minimum front-to-back ratio of 10dBi. By adding the reflector backing, the gain is increased by 1dB for each IFA while the back radiation is reduced by more than 5dB.

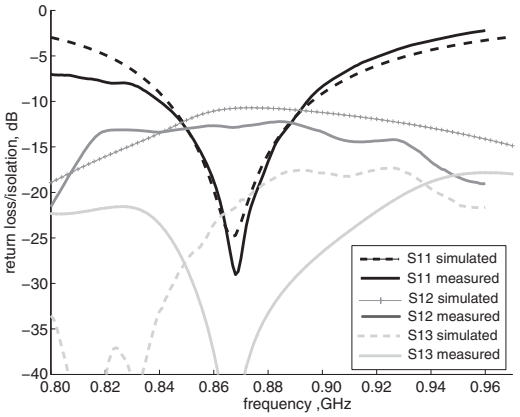

Fig. 2 *Reflection coefficient (Sii) and mutual coupling (Sij)*

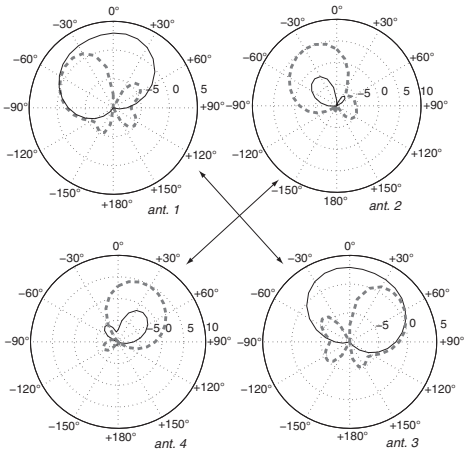

Fig. 3 *Polarisation diversity: simulated radiation patterns E_θ and E_φ in yoz-plane*

E_θ
E_φ

Diversity performance: Fig. 3 shows the angular distributions of the electric field E_θ and E_φ for each IFA in the yoz-plane ($\varphi = 0°$). The E_θ null for IFA 2 at +30° is compensated by a maximum E_θ for IFA 4 and vice-versa for −30° by symmetry of revolution. IFA 1 and IFA 3 exhibit important E_φ values with maxima directed towards −30° and +30°, respectively, while IFA 2 and IFA 4 are characterised by very weak IFA levels. The simulated radiation patterns $10\log(E_\theta^2 + E_\varphi^2)$ of IFA 1 and IFA 3 focus their maximum gain respectively in ±30° in the elevation plane. The same complementarity of gain orientation is observed for IFA 2 and IFA 4. On the other hand, the envelope correlation coefficient has been calculated using the measured S-parameters [7]. In the working band, we find $\rho e < 0.003$ both between the collinear and the orthogonal IFAs. All these results confirm the potentialities of the structure in terms of pattern and polarisation diversities.

Tags readability test: The readability test makes use of 38 passive tags built around meandered dipoles. Each tag is stuck on a small plastic box (4 × 4 × 7cm). Then, the 38 tags are randomly placed into a rectangular cardboard box. The test zone is a pie slice of 3m radius and curvature sector varying from −40° to +40°. The reading rate is evaluated

against the distance between the cardboard box and the reader's antenna and its azimutal angle from the antenna centre. The cardboard box is then moved in the test zone using 10cm radial steps and 10° angular steps (270 measurement samples). The measurements were made in a lab room dominated by the presence of numerous metallic objects (cabinets, measurement equipment) and concrete walls. The cardboard box and the reader antennas are placed 1.1 m above the ground floor. Each of the four IFA ports are connected through coaxial cables to one of the four output channels of the RFID reader Impinj's Speedway R420 [8]. The reader then sequentially switches between the IFAs. In a commercial version, the antenna should be fed by a SP4T connected to one of the reader outputs. The reader delivers 29 dBm to each IFA element which results in a EIRP (equivalent isotropic radiated power) of 29dBm + 5dB = 34dBm. The tags readability with the diversity antenna is compared with a 7 dBic circularly-polarised antenna (Poynting PATCH-A0025 24.5 × 23.5 × 4cm) and a 5 dBi linearly polarised antenna (IMPINJ-A0311-USA 46 × 9 × 2cm). For a fair comparison, reader output powers are adjusted so that identical EIRPs are obtained for each antenna.

Fig. 4 shows the rate of tag readability in the test zone for the three reader antennas: diversity antenna (Fig. 4*a*), CP antenna (Fig. 4*b*) and LP antenna (Fig. 4*c*). As shown in Fig. 4*a*, 100% of the tags have been read by the diversity antenna up to 1.5 metres. Beyond this distance, the rate of tags readability remains above 70% in the measurement area. When the reader is connected to the CP antenna the 100% reading range is shorter, about 1metre (Fig. 4*b*). This readability rate decreases when the cardboard box moves away from the reader. With the CP antenna only 10% of the tags are read at 2 metres compared with more than 80% with the diversity antenna. Unlike the two other antennas, a fluctuation of tags reading with distance is observed for the LP antenna, as illustrated in Fig. 4*c*. Two hot zones where 80% of the tags can be read are identified: the first is below 0.70 from the reader and the second at approximately 2 metres. The reading rate does not exceed 40% elsewhere. The second reading spot at 2 metres is attributed to multipath in-phase combination. These fluctuations are not observed with the diversity antenna where the tag readability rate decreases continuously along the distance. In any case, the reading rate is much larger for the diversity antenna than the two others.

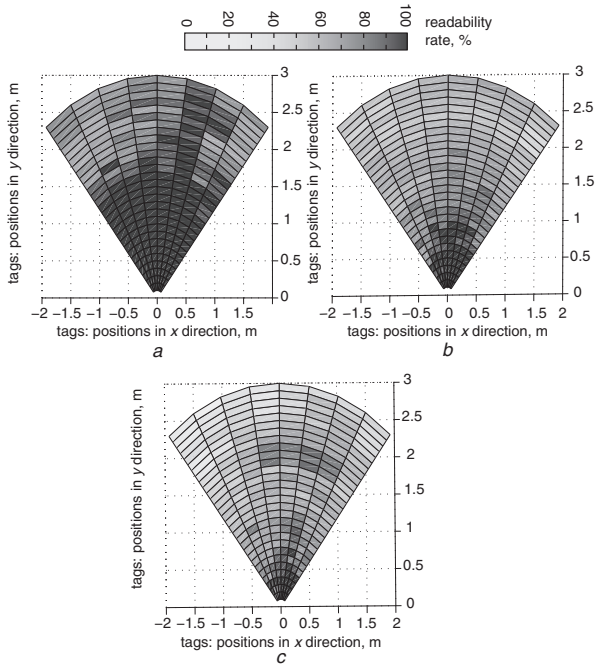

Fig. 4 *Tags readability test*
a Diversity antenna
b CP antenna
c LP antenna

Conclusion: A compact diversity antenna is developed to enhance the readability for a strong density of passive UHF tags in indoor scenarios. By combining space, pattern and polarisation diversities, the proposed antenna offers better reading rates than available commercial RFID reader antennas for equivalent volumes. Associated to an integrated SP4T, and added to classical RFID techniques for reading improvement such as the displacement of the tagged objects and/or the multiplexing of several reader antennas at distant points, the proposed antenna should make possible a convergence to a 100% reading rate much faster than the existing antenna solutions.

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One or more of the Figures in this Letter are available in colour online.

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