

# Near-Field Coupling in UHF-RFID systems

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**Abstract**—In this paper near-field coupling in UHF-RFID systems is investigated. The wireless power transfer among reader and tag antennas is addressed through a numerical model involving different reader antennas and a short-range tag. System performance is investigated in terms of both mutual impedance and power transfer efficiency. Finally, a new near-field reader antenna based on coplanar waveguide technology will be described.

## I. INTRODUCTION

Antennas for radio communication systems (e.g. radio links, cellular networks, WLAN, remote sensing) are designed giving a lot of attention to antenna gain, polarization, radiation pattern characteristics (e.g. half power beam width, front to back ratio, etc.) [1]. All above parameters are defined in the antenna far-field (FF) region, so they are suitable to characterize a communication systems in which the transmitter and the receiver antennas are far enough (*i.e.* distance bigger than  $2D^2/\lambda$ , where  $D$  is the maximum antenna size and  $\lambda$  is the free-space wavelength).

On the other hand, some applications exist that exploit antenna features in its near-field (NF) region. In this context, NF coupling between antennas has been studied since a long time [2] and most researches have been focused on coupling effects in antenna arrays, field sensing for near-field antenna scanning systems, magnetic coupling between loops operating at LF-HF frequency bands. More recently the near-field coupling analysis has been applied to specific short-range radio systems, as for example NFCs (Near Field Communications) [3]-[4], microwave wireless power transfer [5]-[7], as well as RFID (Radio Frequency IDentification) systems [8].

NF coupling in RFID systems, has been firstly exploited at low-frequency (LF, 125-134 KHz) and high-frequency (HF, 13.56 MHz) bands where the reader-tag communication occurs through a near-field inductive coupling, and antennas are usually made of single/multi turn coils (at both reader and tag side). The main feature of the inductive coupling is the robustness with respect to environmental effects (metallic or liquid objects in the tag vicinity). Recently NF-UHF RFID systems have been developed to exploit the electromagnetic coupling that occur in the near-field region with the advantages of the higher reading and data rates typical of UHF systems. A system can be employed for UHF-RFID desktop readers [9]-[11], smart shelves [12]-[14], smart drawers, smart

point readers or smart conveyor belts, [15], and printers/encoders [16].

In Section II of this paper, NF coupling in UHF-RFID systems will be investigated through a numerical model based on commercial reader and tag antennas. In particular, the wireless power transfer is analyzed on the basis of the mutual impedance and the Power Transfer Efficiency (PTE). In Section III, the NF coupling performance of a new NF-UHF RFID reader antenna based on the coplanar waveguide technology will be described. Finally some conclusions will be drawn in Section IV.

## II. WIRELESS POWER TRANSFER IN NF-UHF RFID SYSTEMS

The analytical evaluation of the electromagnetic coupling in the near-field region is a quite difficult task, and some results are limited to configurations involving simple antenna models [5]. In [17], the reciprocity theorem has been used to evaluate NF coupling between some antenna models for which a known source distribution can be assumed (loop, dipole or patch antennas). On the other hand, maximizing the wireless power transfer between reader and tag represents a key issue in improving NF coupling in UHF-RFID systems. Therefore, to account for the influence of different tag (e.g. dipole like, hybrid configuration) and reader (e.g. segmented loop, patch antennas, travelling wave antennas) antenna shape and input impedance, and antennas relative orientation/position, full-wave numerical simulations are more suitable to give general and practical results. Numerical simulations are also more convenient than expensive and time-consuming measurement campaigns, which can be obtained only for a limited set of tag-reader antennas configurations.

In this section, on the basis of the numerical analysis of the antenna coupling presented in [8], the NF coupling has been investigated by considering typical commercial antennas at the reader side, like patch and loop antennas. At the tag side, a short range UHF RFID tag has been considered (UH113 LABID). As in [8], the case of a reader antenna identical to the tag antenna has been considered, namely a "matched-antenna" case that resembles the well-known matched-filter concept widely used in communication receivers and radars. The latter solution can be adopted for those applications in which the distance among reader and tag antennas are fixed (e.g. printers/encoders).

The impedance matrix model adopted for the analysis of the

NF-UHF RFID radio link is represented in Fig. 1. It results from considering the tag and reader antennas, and the space between them, as a linear two-port network.

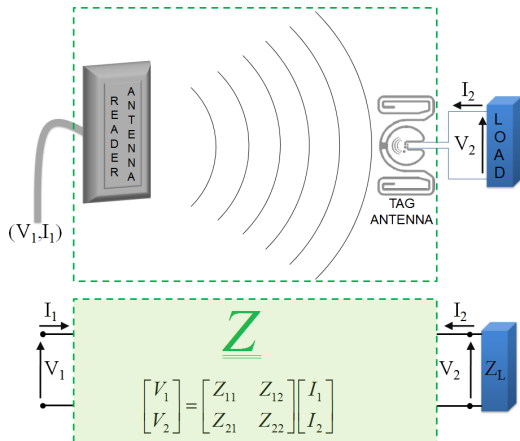


Fig. 1. NF-UHF RFID system scheme with reader antenna and tag antenna connected to a load and the equivalent linear two-port circuit described by the  $\underline{Z}$  matrix and the impedance load  $Z_L$ .

Firstly system performance is addressed in terms of mutual impedance at the UHF central frequency of  $f_0=910$  MHz (Fig. 2). Curves reach the  $1/d$  algebraic decay for a distance near to 30 cm, so the near-field coupling occurs within this distance (after which antennas can be considered in the far-field region). For the case of a reader antenna equal to tag antenna (*i.e.* matched antenna configuration), a peak occurs in the mutual impedance at a distance of around 2.4 cm, showing that it is possible to maximize power transfer performance for those applications in which the reader and tag antennas distance is fixed and known.

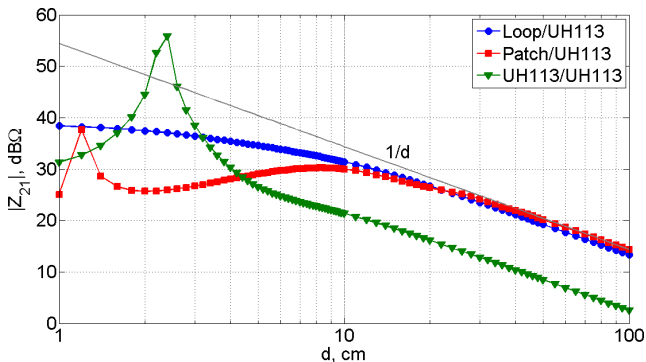


Fig. 2. Mutual impedance  $Z_{21}$  versus distance for the NF-UHF RFID system configurations at  $f_0=910$  MHz: Loop/UH113 (circle markers), Patch/UH113 (square markers) and UH113/UH113 (triangle markers).

The other performance parameter we considered is the Power Transfer Efficiency ( $PTE$ ) that represents the ratio between the power dissipated at the load of the tag antenna, and the input power accepted by the reader antenna:

$$PTE = \frac{P_T}{P_R} = |Z_{21}|^2 \frac{\Re\{Z_L\} / \Re\{Z_{in}\}}{|Z_L + Z_{22}|^2}$$

While the mutual impedance only depends on antennas characteristics, the  $PTE$  depends also on tag load impedance  $Z_L$ . To evaluate realistic tag-antenna loadings, the  $PTE$  has been evaluated for the case of complex conjugate of the tag antenna input impedance (the latter evaluated when the tag is in the far-field region of the reader antenna, that is in free-space) and for the case of optimum load [18] to get a performance upper bound.  $PTE$  versus distance (within the near-field region) is represented in Fig. 3, for different reader antennas and the UH113 tag, at the UHF central frequency of  $f_0=910$  MHz. For all considered configurations, it is clearly notable the difference among  $PTE$  and  $PTE_{max}$  for lower distances ( $d < 10$  cm), after which curves overlap. This is due to the fact that the load impedance is calculated as the complex conjugate of the tag antenna when it is in free-space (*i.e.* far-field region), but this condition cannot be satisfied if the tag antenna is close to the reader, namely the complex conjugate load is different from the optimum load for short distances. The solution with a loop antenna determines high stable  $PTE$  values within 4 cm from the antenna, after which it decreases.  $PTE$  of the patch solution becomes higher with respect to the other configurations after a distance of 5 cm. Finally the matched antenna configuration allows better  $PTE$  performance for small values of distance ( $d < 4$  cm). This analysis suggests that on the basis of the application, different reader antenna solutions can be adopted to maximize the power transfer. Investigation on other tag configurations are under progress to demonstrate to reliability of the above results relating to different reader and tag antennas.

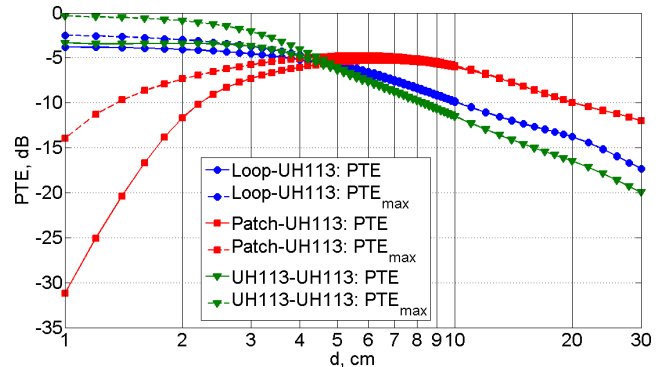


Fig. 3.  $PTE$  (solid line) and  $PTE_{max}$  (dashed line) versus distance for the NF-UHF RFID system configurations at  $f_0=910$  MHz: Loop/UH113 (circle markers), Patch/UH113 (square markers), UH113/UH113 (triangle markers).

Until now a polarization matching condition among linearly polarized antennas has been considered. However, in realistic scenarios the tag can be arbitrary oriented with respect to the reader antenna and this degrades  $PTE$  performance as shown in Fig. 4. The matched antenna configuration allows higher  $PTE$  values, but at least a 5 dB difference from the polarization matching case is observed. In any case for RFID printers/encoders the orientation among antennas can be controlled and this problem can be overcome.

Furthermore it is worth noting that NF coupling is also of interest for recently suggested RFID tag-to-tag

communications [19]. In such systems the cross-link among tags should be characterized accounting for the mutual coupling among the "talker-tag" and the "listener-tag" [20]. So, also in this case a two-ports network model could be applied.

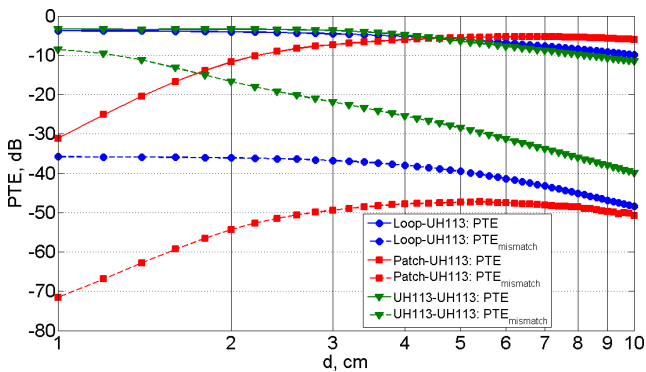


Fig. 4. PTE versus distance for the NF-UHF RFID system configurations at  $f_0=910$  MHz in polarization matching (solid line) and polarization mismatching (dashed line) configurations: Loop/UH113 (circle markers), Patch/UH113 (square markers), UH113/UH113 (triangle markers).

### III. NF-UHF RFID READER ANTENNA

As already mentioned, in NF-UHF RFID systems communication occurs through electromagnetic coupling among antennas in the near-field region. For this reason a proper reader antenna design can be helpful to improve performance on the basis of different applications (e.g. desktop readers, smart shelves, smart conveyor belts). As observed in the previous section, one of the most important feature is that antenna performance should be robust with respect to the tag orientation.

Known solutions are typically loop antennas (resembling the approach used in HF-RFID systems); since the field intensity depends on the antenna diameter, loops are typically implemented with a segmented configuration. Thus loop elements are connected by a capacitive load [10] or inductively coupled [11]. The above solutions are resonating antennas, thus their sizes depend on the operating frequency and are not easily scalable to be adapted for different NF-UHF RFID scenarios.

For this reason more recently Travelling Wave Antennas (TWAs) have been considered for NF-UHF RFID reader antenna design [12]-[15]. With respect to resonating antennas, TWAs design is not related to the operating frequency, thus their shape can be arbitrary chosen to maximize the electromagnetic field amplitude close to the antenna itself and to avoid dead zone on the antenna surface. So they represent low-cost, scalable, wideband, and low-profile solutions.

In [14] a single straight microstrip line has been presented for a NF-UHF RFID reader (865-928 MHz). A modified version with slight meanders has been also designed for conveyor belt applications [15]. In this case, it has been demonstrated that the presence of meanders significantly enhanced each electromagnetic field components in the near-field region

(while they still remain confined around the structure boundary).

On the basis of TWA features, the authors recently proposed to employ coplanar waveguide (CPW) technology [9] for the reader antenna design, since it can maximize the electromagnetic field distribution just above the antenna substrate. The proposed idea has been demonstrated on a desktop reader antenna for UHF-RFID systems. A meandered CPW (named as *Snake Antenna*) has been designed to create an electromagnetic field distribution as uniform as possible on the antenna surface.

The antenna layout and stackup are depicted in Fig. 5 ( $S=4.6$  mm,  $W=2$  mm). A 150- $\Omega$  CPW line has been realized on a 0.73-mm-thick FR4 substrate; the CPW line is closed on a matched load, to avoid a standing wave (non-uniform) field pattern on the antenna surface. In particular, this antenna has been designed to confine the electromagnetic field amplitude in the antenna near-field region, in order to detect tags in a distance range up to around 10 cm from the antenna surface. A reflector plane is also considered in order to make the reader quite independent from the desk material properties.

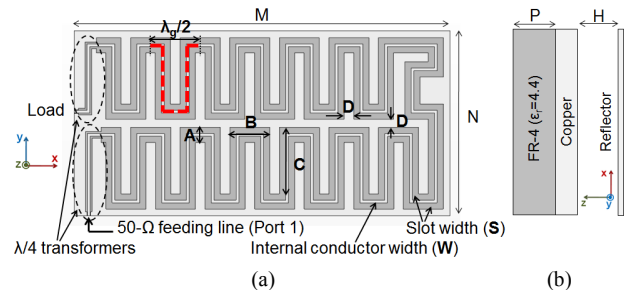


Fig. 5. *Snake Antenna* (a) top view of the layout and (b) stackup. The main geometrical parameters are:  $A=11$  mm,  $B=29$  mm,  $C=49$  mm,  $D=7$  mm,  $M=275$  mm,  $N=135$  mm,  $H=10$  mm,  $P=0.73$  mm.

The antenna reflection coefficient satisfies system requirement in the UHF-RFID frequency band. Both electromagnetic field components parallel to the antenna surface (x-oriented and y-oriented) are excited since the meandered CPW structure has stretches aligned along both directions as shown by the magnetic fields distributions in Fig. 6.

A numerical investigation on the antenna power transfer efficiency is actually under development and numerical results will be shown at the conference. From this, the aim is predict the antenna read range and to compare it with measured results obtained with different tag topologies.

An interesting open problem regarding antenna design for NF-UHF readers is which type of field component should be maximized to improve the NF coupling. In HF-RFID systems just the magnetic field is investigated since the communication occurs through an inductive coupling. Conversely, in UHF-RFID systems both the electric and magnetic field components are useful since, as already said, tag antennas are often dipole-like or hybrid configurations. This will be subject of further investigations.

It is worth mentioning that desktop reader antennas can also be employed to detect stacked tags for Item Level Tagging

(ILT) or smart cash desk applications. Thus read range performance for standalone tag can be modified due to the mutual coupling among nearby tags [21]-[22]. Read range measurements on the *Snake Antenna* will be also done to verify this phenomena and to understand if it is possible to determine an optimum distance among tags to maximize reading performance even when tags are lined up. To this aim, a numerical investigation can be done through a numerical model as in [8], with an  $N$ -ports network.

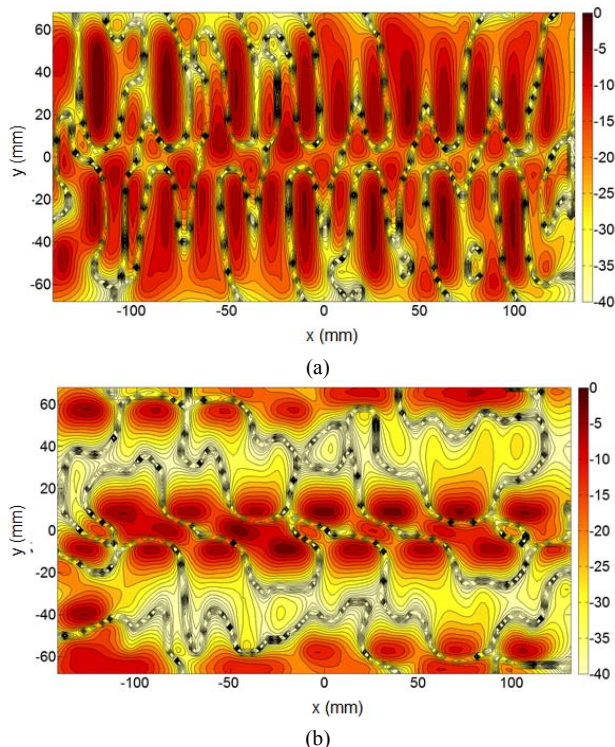


Fig. 6. Normalized simulated magnetic field (dB) on the  $xy$ -plane ( $275 \times 135 \text{ mm}^2$ ) at a distance of 1 cm from the *Snake Antenna* surface: (a)  $H_x$ , (b)  $H_y$ .

#### IV. CONCLUSION

Near-Field coupling in UHF-RFID systems has been investigated. A two-ports numerical model has been adopted to characterized reader and tag antennas and the space among them. Both the mutual coupling and the power transfer efficiency have been evaluated for different reader antennas and a short-range tag. A preliminary design of a new NF reader antenna based on coplanar waveguide technology has been described. Thanks to a meandered structure, both electromagnetic field components parallel to the antenna surface are excited allowing for reliable performance with arbitrary oriented tags.

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