Modular Antenna for Reactive and Radiative Near-Field Regions of UHF-RFID Desktop Readers

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Abstract

A general and reconfigurable antenna scheme for RFID desktop readers operating in the UHF band is here proposed. To maximize the electromagnetic field in a confined volume within the antenna near-field region (namely, in both the reactive and radiative near-field regions), a travelling wave antenna is combined with a low-gain resonating antenna, which share the surface of the desktop reader antenna. The travelling wave antenna allows for covering the reactive near-field region, with almost uniform electric and magnetic fields up to a few cm from the antenna surface. The low-gain resonating antenna is used to cover the radiative near-field region, up to a few tens of cm from the antenna surface, yet radiating a relatively low field in the antenna far-field region as required by antennas for desktop readers. In such a way, a satisfactory tag readability is expected independently on the material of the item the tag is attached to and the effect of the mutual coupling among stacked tags. The suggested modular configuration can be realized by using different technologies for the travelling wave antenna (microstrip, coplanar waveguide, slotline, etc.), as well as different layouts for the resonating antenna. Above degrees of freedom allow the antenna designer to easily meet the specifications on antenna size and RFID read range. The antenna modules used to realize the reader antenna can be combined through either a shunt or series feeding connection; as an alternative, a few switches and variable power splitters could be added to implement a reconfigurable desktop reader antenna.

1. Introduction

Radio Frequency IDentification (RFID) systems are largely used in practical applications such as anti-counterfeiting, logistics, warehouse management, to efficiently identify, track and manage items. On the basis of the operating frequency band, it is possible to distinguish two main RFID classes: HF RFID system (13.56 MHz) and UHF RFID system (865-928 MHz). HF RFID systems are short-range communication systems which can find application in Item Level Tagging (ILT), in pharmaceutical and retailing industry. Since the tag is powered up through the magnetic field (inductive coupling), these systems are not susceptible to the presence of liquids or other dielectric and conductive materials in the tag proximity (loop antennas are typically employed). On the other hand, UHF RFID systems are able to detect tags at longer distances (up to meters) since reader antenna and tag communicate through electromagnetic waves. Besides, they are able to transmit a larger amount of data in a shorter time, and small and low-cost tags can be used, even if they are more susceptible to the presence of surrounding materials. More recently, Near-Field (NF) UHF RFID systems have been developed for those applications where reader antenna and tags are in the near-field region of each other [1]-[4]; they keep the typical advantages of UHF RFID systems, with an improved robustness with respect to the effects of metals and liquids nearby the tag, as in the HF RFID systems. While a large number of antenna solutions have been proposed in the open literature for UHF RFID systems oriented to far-field applications (*e.g.* patch antennas [5], slot antennas [6] and inverted-F meandered dipoles [7]), the near-field antenna design appears more challenging. Indeed, differently from conventional far-field antennas, near-field antennas have to be able to confine the electromagnetic field in proximity of the antenna, by generating a strong and uniform electromagnetic field in the whole interrogation area just above the antenna surface. Different antenna technologies can be adopted, depending on the specific application. As for example, in RFID portals a near-field focused array [8]-[11] can be adopted to get a few meters read range, while in RFID desktop readers, a segmented loop antenna [12]-[13] or a travelling wave antenna [14]-[18] can be designed to have a read range less than a few tens of cm. In the framework of UHF RFID desktop reader applications, it is worth noting that, the item material the tag is attached to and the mutual coupling among tags in a stacked configuration can compromise the tags readability and reduce the read range. For this reason, it could be useful to design desktop reader antennas that in unloaded condition exhibit a read range larger than that required in real operational conditions. Also, reconfigurable antennas can be considered, which allow for a shaping of the interrogation field in the antenna near-field region, when a simple control of the reader output power is not enough to guarantee high reading percentages on the whole antenna surface and for any tagged item and tag topology/orientation.

In this paper a modular antenna scheme for NF-UHF RFID desktop readers is presented to face with most of the above mentioned issues. The main idea is to maximize the electromagnetic (EM) field within the reactive and radiative near-

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field regions of the desktop reader antenna, by employing two antenna modules, each one optimized for one of the above regions. After a brief overview of the specifications for NF-UHF RFID antennas (Section II), the new modular antenna operating principle is described in Section III. Finally, some conclusions are drawn in Section IV.

2. Near-Field Antenna main operating characteristics

Near-field antennas are employed in different UHF RFID applications, such as in smart point readers, gates on conveyor belts, smart shelves and desktop readers. In particular, in desktop reader applications, a well-known antenna solution for NF-UHF RFID systems is represented by segmented loop antennas [12]-[13]. Differently from solid loops, a segmented loop antenna provides a strong and uniform magnetic field close to the loop itself, despite of its size is electrically large or comparable to the wavelength. Since segmented loops are resonating antennas, they represent a not-scalable solution. Besides, Travelling Wave Antennas (TWA) [14]-[18] represent an easily scalable solution, since their length and shape are not strictly related to the operating frequency (non-resonating structures). These antennas basically consist in transmission lines ending on a matched load to avoid the generation of a stationary wave above the antenna surface. Furthermore, the matched load reduces the antenna efficiency; such a lower efficiency and the TWA low-directivity, both help to radiate a low field in the far-field region (low antenna gain is required to avoid false readings). Then, a printed TWA represents a low-cost, scalable, wideband, and low-profile solution that can be realized by exploiting coplanar waveguide (CPW) [14]-[15], microstrip [16]-[17] or coplanar stripline [18] technologies.
The main operating characteristics relating to NF UHF-RFID antennas for desktop reader applications can be summarized as in Table I.

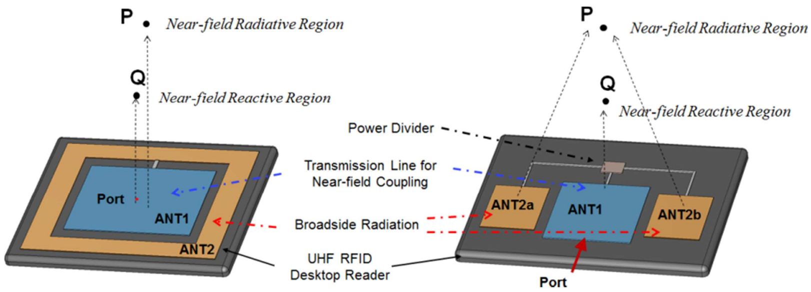
TABLE I
MAIN FEATURES OF ANTENNAS FOR NEAR-FIELD UHF RFID DESKTOP READERS

Antenna feature	Specifications	Notes
VSWR	Less than 1:1.5	To limit the power reflected toward the reader RF front-end
Far Field	Low directivity and radiation efficiency, to limit far-field antenna gain (Antenna gain around –4/-8 dBi)	To limit false readings relevant to tags that are located out of the desktop reader surface. Antenna gain less than -10dBi will determine low performance in the radiative near-field region, especially when the tags are attached to conductive items or in presence of multiple stacked tags.
Near Field	As uniform and high as possible on the antenna surface, for given reader output power and reader antenna surface extension. Low field amplitude behind the reader antenna.	To allow successful reading performance independently on tag location on the reader antenna surface, tag spatial orientation, tag topology, and properties of the table the reader is put on.
Polarization	Electric and magnetic energies almost uniformly distributed among all the near-field components. Circularly polarized field (axial-ratio less than 3dB in the direction normal to the antenna surface), in the radiative near-field region.	To allow successful reading performance independently on tag spatial orientation
Layout	Thin and scalable in size	To fit with application and market requirements

The design of antennas matching most of the requirements listed in Table I, is quite challenging as a number of specifications on the near-field properties are added to conventional requirements for far-field antennas (gain, back radiation, input impedance, far-field pattern and polarization). For example, travelling wave antennas are a natural choice to get an almost uniform field on the antenna surface but it is not easy to satisfy requirements on field polarization and antenna gain.

3. Modular antenna operating principle

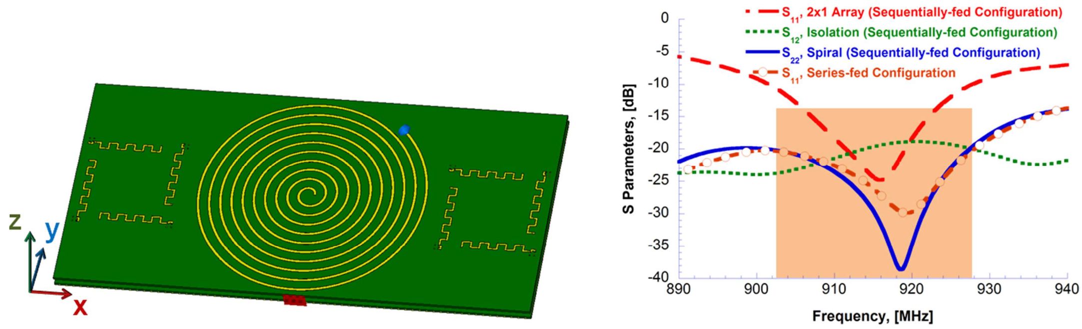
When trying to satisfy the requirements in Table I, a possible choice consists in the combination of two antenna modules used to separately match specifications in the two regions of interest, namely the radiative and reactive near-field regions (Fig. 1). The first module is a TWA (namely, a transmission line designed to increase the field on the antenna surface with respect to a conventional low losses microstrip or CPW transmission line). A spiral or a meandered structure is preferred to uniformly distribute the EM energy among all the field components [14]-[15]. The TWA module has to be located in the middle of the reader antenna surface, which represents a premium location since it is the region where a tagged item is more likely to be located. The region surrounding the TWA antenna can be used to place one or two resonating antennas that are supposed to cover the radiative near-field region with a circularly polarized field. Since most of the antenna surface has to be devoted to the TWA antenna, resonating antenna module has to be realized with miniaturized antennas. It is worth noting that the miniaturization helps to meet the requirement on low antenna gain. As an example, two possible configurations are sketched in Fig. 1. ANT1 is a TWA whose end is connected to a resonating antenna that could be a loop-like antenna (Fig. 1a) or a broadside array made of two miniaturized CP patches (Fig. 1b). Differently by TWAs closed on a matched load [14]-[18], in the proposed configuration the power at the end of the lossy transmission line is used to radiate a field contribution in the radiative near-field region. Moreover, the series-feeding helps to get a very low reflection coefficient at the antenna input, so allowing a simpler design able to match requirements on the allowable antenna size. Depending on the particular application, it is possible to optimize the radiating elements typology as well as their position on the antenna surface. The degrees of freedom available in the proposed layout allow the antenna designer to easier meet most of the requirements for desktop reader antennas; also, the proposed modular antenna can be easily scaled to fit with reader cases of disparate size. The orientation and layouts of the two antenna modules have to be chosen by considering that the mutual coupling between the radiators sharing the antenna surface is not negligible, as the radiating elements will be close to each other and operate at the same frequency band. Moreover, miniaturized antennas usually are narrow band antennas, and this will make difficult to design reader antenna covering both ETSI and FCC



(a) (b)

Fig. 1 – General scheme of the modular antenna for NF-UHF RFID desktop readers: (a) configuration with central near-field travelling wave antenna surrounded by a loop-like resonating antenna, and (b) configuration with a central near-field travelling wave antenna and a series-fed array made of two miniaturized resonating antennas.

In Fig. 2a a possible modular configuration is shown as well as preliminary results in terms of S-parameters in the FCC UHF RFID operating band (902-928 MHz). In this example, a microstrip spiral-shaped transmission line antenna is placed in the central area, and a 2x1 inverted-F meandered dipoles [7] array is realized in the lateral zone near the edges. While the transmission line is responsible for the EM field generated just above the antenna surface (near-field reactive region), the 2x1 array can be properly fed in order to maximize the EM field in the near-field reactive region. The two radiating elements can be series-fed or, alternatively, connected to a switch and sequentially fed by using a proper power control algorithm in order to meet the NF-UHF RFID desktop reader requirements.



(a) (b)

Fig. 2 – (a) Possible configuration of the proposed modular antenna and (b) preliminary simulated S-parameters.

It is worth noting that the proposed modular antenna resembles reader antennas for NF-FF applications [19]- [22], where two antennas are combined to contemporarily cover the near-field region and the far-field region. Such solutions consist of a square patch with a segmented loop antenna [19]-[20], a distributed capacitor loaded segmented loop with a backed metallic plate [21] and a folded-dipole loop antenna [22]. .

4. Conclusion

A general and reconfigurable scheme for NF-UHF RFID desktop reader antenna has been described. In order to get a confined detection volume within the near-field region, the proposed scheme foresees the combination of a NF travelling wave antenna placed in the central area of the desktop reader and a low-gain resonating antenna placed close to the border. The two antenna modules can be series-fed or alternatively sequentially-fed through a switch and with a proper power control, in order to match with the typical near-field desktop reader antenna requirements. Preliminary results in terms of S-parameters in the FCC UHF RFID operating band (902-928 MHz) for a particular antenna configuration have been shown.

5. References

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