Miniaturized all-angle accessible RIFD tag

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Abstract. Radio frequency identification (RFID) is one of the commonly used approaches to a short-range wireless data exchange. Numerous passive RFID tags are available on the market, and in a vast majority of cases, their designs are based on flat meandered dipole architectures. However, besides technological advantages, those realizations suffer from polarization mismatch issues and limited spatial sectors, from which flat tags can be interrogated. Here, we demonstrate and analyze a miniature omnidirectional tag accessible from all 4π stereo angles with a commercial RFID reader.

1. Introduction

Radio frequency identification (RFID) is one of the commonly used approaches to a short-range wireless data exchange. This topic keeps advancing owing to new emerging applications, including Internet of Things (IoT) and many others. Passive RFID tags can power this technology, but need to comply with several specifications, including long reading distance, omnidirectional response, low cost realization, and small footprint. However, those requirements are challenging to accommodate on the same platform. The main electromagnetic challenge is reducing the physical sizes of the tag’s antenna implies a decrease of efficiency and bandwidth. There are many approaches to reducing the antennas area, such dipole meandering, commercial sub-centimeter designs, as a rule, have a short range and cannot be investigated from a distance of more than a meter [1], [2], [3].

Obtaining an ideal omnidirectional linearly polarized radiation pattern is fundamentally impossible [4],[5]. However, various designs have been developed to achieve ideal performance [6],[7]. Typically, typical dipole RFID tags operate with a single dipole resonance and have a donate radiation pattern. To obtain a radiation pattern close to uniform, several multipoles must constructively interfere, creating a spherical wavefront in the far zone. A possible solution in this area is to use a combination of resonances and materials with a high refractive index. These concepts have recently been explored in the field of RFID [8],[9].

Here we demonstrate a omni-RFID tag design, which complies with all of the beforehand mentioned requirements. Our experimental realization shows the capability to perform all-angle readout from a several meters distance while the overall size of the tag is 3cm.

2. Electromagnetic simulations

2.1 Design

Schematics view of the omni-RFID tag is shown on Fig.1. Design consists of several main components: folded metal strip shaped like an omega particle [10] with folded arms, placed near the split ring’s gap, which control the antenna's electrical length and the T-matched configuration is optimized to impedance match the chip (integrated circuit (IC) (Impinj Monza 4 chip)) to the antenna. Overall, the geometry is similar to a recent report [6]. To reduce the area occupied by the volumetric tag, we immersed the metal strip in a ceramic sphere with a high refractive index. Omni-RFID is optimized to operate in 860-930 MHz, which is in accordance with the EPCGEN2 RFID standard, and the IC’s impedance values are taken from the vendor’s datasheet.
2.2 Numerical analysis

RFID communication involves downlink (requesting a tag by the reader) and uplink (transmitting a time-modulated signal back to the reader). The structure was developed by full-wavelength numerical simulations implemented with a CST Microwave Studio frequency domain solver (FEM). To probe the uplink, the tag is considered an active antenna. To do this, instead of a microcircuit, a discrete 50 Ohm port was inserted into the gap and the far fields of such an antenna were taken into account. The geometry of the entire structure has been optimized to minimize the size of the mark and to achieve an isotropic radiation pattern. The deterioration in the uniformity of the radiation pattern was compensated for by introducing the ellipticity of the initially spherical mark. The final set of parameters is shown in Table 1.

| Parameter          | Axis | Value     |
|--------------------|------|-----------|
| Omni-RFID tag      | x    | 25 mm     |
| Omni-RFID tag      | y    | 25 mm     |
| Omni-RFID tag      | z    | 18 mm     |
| Diameter split ring|      | 17.7 mm   |
| Folded wires       |      | 3.4 mm    |
| T-matched          |      | 9.5mm/1.8mm|
| Permittivity of ceramics | | ε=9, tg=0.001 |

Table 1. Parameters of the omni-RFID tag.

To receive a response from any interrogation angle of omni-RFID tag, the antenna of the reader will be triggered between two states, emitting right and left circular polarization. The triggering rate is 5 ms, which complies with the link standards (it takes 1-2 ms slot to scan a tag).

To verify the downlink efficiency, the reciprocity principle can be applied [11]. The main optimization criterion in our case was the value of the current flowing through the microcircuit. The Impinj Monza 4 IC requires 3.7 mA RF current to activate (experimentally determined).

To make a numerical comparison our omni-RFID tag and a commercial tag were placed at 1.5 meters from the Helix antenna. Antenna radiated 0.51 W total power. Both RFID tags use the chip Impinj Monza 4 IC: Impedance of 11-143j (at 915 MHz) in one state, whereas the second is a short circuit. In numerical simulation, the tags were rotated in all planes (XY, XZ, and ZY) and were irradiated sequentially by right and left circularly polarized waves generated by a triggered Helix antenna. The RF current was calculated for all polarizations for both RFID tags (Fig. 2b,c). Figure 2 (a) shows the maximal current in the logarithmic scale through the IC as a function of the tag’s rotation angle. Gray area for modes below the activation threshold. This result shows close to the omnidirectional response of our design, which can collect the field from any direction of incidence and raise the IC above the activation threshold. On the other hand, the commercial dipole tag is not readable from multiple sectors.
Figure 2. Numerical results of RF current flowing through the tag chip versus rotation angle in three different planes (XY, XZ and ZY). Schematics view (b) new omni-RFID tag and (c) commercial RFID. Gray shaded area on the plot demonstrates the regime, where commercial tags can’t reach the activation threshold. RFID IC - Impinj Monza 4.

3. Results

An omni-RFID tag was made as follows: a metal strip was cut from a copper sheet (0.05 mm thick) and an RFID chip was soldered into the gap, detached from the commercial tag. I used an Impinj r2000 reader operating in the frequency range 865-868 MHz (European standard). The housing was 3D printed and filled with a ceramic powder with a dielectric permittivity of 9. The metal strip was embedded in the ceramic powder.

All measurements were performed in an anechoic chamber. The Impinj r2000 reader was connected to a laptop via a USB port, and the amplitudes of the received signals were monitored via the vendor's software. As an antenna of reader used a custom-made Helix antenna with right and left windings, capable of radiating left and right circularly polarized waves, operating in an 850-930 MHz frequency range. We connect two ports of our antenna, applying 0.2 kHz switching with a 50:50 duty cycle.

The tags were placed on a rotating table at 1.5 m from the reader's antenna (Fig. 3a). The tags were rotated alternately in three planes with a step of 10º, which was enough to demonstrate the omnidirectional properties. The received signal intensity was monitored for each physical position of the tags.

Figures 3 (b) and (c) show the dependence of the received signal strength on the rotation angle in three different planes (XY, XZ and ZY) for our isotropic and commercial RFID tags, respectively. You can see that our design significantly outperforms its commercial counterpart in terms of signal-to-noise ratio and angular coverage. The commercial tag is not available from the large angular sector in the case of XY plane rotation (the back reflected modulated signal is below the sensitivity of the reader (-90 dBm)), since the tag operates in dipolar resonance. Our isotropic tag, powered by a combination of an electric dipole and a magnetic quadrupole, gives us all-angle coverage and omnidirectional operation, which was the goal.
4 Conclusions

Demonstrated numerical simulation and experimentally setups new design of small passive RFID tag with omnidirectional response. Omni-RFID tag has a size less than 3 cm due to use high-index ceramic and is read from any angle by an antenna having left and right circular polarization. Reading from any angle is achieved by overlapping several multipole resonances. Such omni-RFID tags can be applied in many applications especially logistic, IoT, vehicle.

Acknowledgments

The work was supported by the Russian Science Foundation (Project 19-79-10232). P.G. acknowledges partial support of the ERC StG “In Motion” (802279), PAZY Foundation, and Israeli Ministry of Science and Technology (Project “Integrated 2D & 3D Functional Printing of Batteries with Metamaterials and Antennas.”

Figure 3. (a) Photo of experimental setup: RFID reader with a custom-made Helix antenna with two spiral, rotation table and the omni-tags. The power of the backscattered signal (in dB) at the reader depending on the angular orientation of the tag in three different planes (XY, XZ and ZY) (b) our omni-RFID tag and (c) a commercial RFID tag.
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