Design and RFID Signal Analysis of a Meander Line UHF RFID Tag Antenna

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Introduction

Radio frequency identification (RFID) systems use electromagnetic waves to transfer identification data at radio frequencies. A typical passive UHF RFID system consists of a reader system and microchip-controlled tag attached to the object to be identified. The identification data of an object is stored in the chip. If the tag is located inside the reader's interrogation zone it gets enough energy from the reader's electromagnetic fields to activate the chip, which then modulates the identification data to the carrier signal and backscatters it to the reader. [1],[2]

In applications small tag size is desirable for low fabrication costs and also the small size is suitable for tag placement because free space on product packages may be very limited. Moreover, wide operating frequency range is preferable so that the identification of objects is not restricted to a specific geographical area by the local RFID frequency range.

The aim of this study was to design a wideband dipole-type RFID tag for global UHF RFID frequencies, by utilizing a meander line structure to reduce the tag size without significantly degrading its performance. The performance of the designed antenna is analyzed with threshold and backscattered power measurements and radar cross section (RCS) calculations. The performance of the designed tag antenna is compared with dipole-type commercial tags.

Proposed antenna structure and theoretical considerations

At the UHF frequencies the wavelength is typically large compared to the tag size. Theory suggests that electrically small dipoles have a similar omnidirectional radiation pattern as the ideal half-wavelength dipole [3]. This is a desirable feature for an RFID tag, but on the other hand short dipoles are inherently inefficient radiators [3] and thus have low gain and consequently short readable range.

One way to tackle this trade-off between antenna size and performance is to use meander line structure to increase the electrical length of the antenna while keeping its physical dimensions reasonable for applications. In [4] it is proposed that folding the antenna in a meander produces both capacitive and inductive reactance so that they cancel each other. Therefore resonances can be achieved at lower frequencies than with straight antenna structure. For simplicity a periodic...
meander was used in this design, although in [5] it is suggested that this may not lead to optimum gain.

Matching network with wideband characteristics was developed to provide good impedance matching through the desired frequencies. Antenna material is copper (thickness 0.1 mm) and polyethylene was used as a substrate (thickness 0.15 mm). Fig. 1 presents the most crucial dimensions of the antenna design.

![Matching Network](image1)

**Figure 1: Dimensions of the tag in millimetres.**

**Simulations and impedance matching**

This design utilizes the Alien Gen2 UHF RFID integrated circuit (known as the Higgs Chip), whose impedance was approximated to be $(17-j145) \, \Omega$. Tag was modelled with a FEM simulator and the dimensions of the triangular gap in the matching network and length of the meander parts in the longitudinal direction were found to have the most crucial effect on the antenna impedance. The height of the meander parts wasn’t as much deciding factor and therefore it was fixed to 20 mm. Afterwards the rectangular gap was added to the matching network to fine-tune the antenna impedance. In general this matching network proved to offer wide possibilities to adjust the antenna impedance, reactance in particular.

![Power Reflection Coefficient](image2)

*Figure 2: Simulated power reflection coefficient.*

![Antenna Impedance](image3)

*Figure 3: Simulated antenna impedance.*

Abovementioned dimensions were optimized using a Sequential Non-Linear Programming (SNLP) -algorithm with a cost function composed of $S_{11}$-values at three different frequencies; 865 MHz, 915 MHz and 965 MHz. Radiation
characteristics were evaluated separately when choosing the dimensions which would yield the best overall performance.

Simulated power reflection coefficient [9] is presented in Fig. 2 and antenna impedance versus frequency is plotted in Fig. 3. Gain pattern for this tag is omnidirectional, doughnut-shaped pattern (typical dipole radiation pattern), with peak gain of 0.55 dBi. In H-plane gain is over 0 dBi in all directions.

**Measurements**

Impedance matching determines how effectively the power captured by the tag from the reader signal is delivered to the IC chip. The chip needs a certain amount of power to operate and the minimum (threshold) power transmitted from reader that is sufficient to power up the chip at a given frequency, can be used to determine the matching performance versus frequency.

However, the readable range of the tag depends also on the strength of the backscattered signal at the receiver of the reader. Differential Radar Cross Section (ΔRCS), which is discussed in [7], is a quantity that determines the power of the modulated backscattered signal, and therefore analyzing the ΔRCS of the tag versus frequency gives us another way to study the readable range of the tag.

In the measurements conducted for this article it was assumed that impedance matching was ideal, i.e. there would be no reflections in the matched non-reflective state of the tag. All the backscattering would occur in the mismatched reflective state of the tag. Small amount of backscattering occurs in practice also in the matched state due to non-idealities in the impedance matching between tag antenna and IC chip.

Measurements were carried out with Voyantic RFID ‘Tagformance’ measurement system [6], which provides an automatic power-frequency sweep to find the threshold power and backscattered signal strength corresponding to each frequency. Distance between reader/receiver antenna and the tag was 1 m and gain of the transmitter and receiver antennas was 9.5 dBi. Results of this measurement are presented in Fig. 4, Fig. 5 and Table 1. For comparison, measurement results for two commercial, short dipole-type, Gen2 tags for global UHF RFID frequency range are also presented. Outer dimensions of these comparison tags are 95 x 8.2 mm and 95 x 7 for Tag1 and Tag2, respectively.

![Figure 4: Transmitted (threshold) power versus frequency.](image1.png)

![Figure 5: Received (backscattered) power versus frequency.](image2.png)
Table 1: Measured $\Delta$RCS values.

<table>
<thead>
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<th>865 MHz</th>
<th>915 MHz</th>
<th>965 MHz</th>
</tr>
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<td>MLA</td>
<td>-19.2 dBsm</td>
<td>-20.5 dBsm</td>
<td>-21.7 dBsm</td>
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<td>Tag1</td>
<td>-24.8 dBsm</td>
<td>-25.0 dBsm</td>
<td>-24.8 dBsm</td>
</tr>
<tr>
<td>Tag2</td>
<td>-31.8 dBsm</td>
<td>-27.4 dBsm</td>
<td>-25.5 dBsm</td>
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Figure 4 shows that the measured threshold power for MLA is lower than for the other tags through the whole frequency band of interest, which verifies the simulated wideband characteristics of impedance matching. Measured $\Delta$RCS values (Table 1) for Tag1 and Tag2 are quite typical for tags of this size. Also in this respect MLA shows a good performance; measured values are higher than ones for comparison tags at all three frequencies.

Conclusions
A meander line UHF RFID tag antenna with an efficient matching network has been designed. Wideband matching and good radiation properties were achieved in parallel with small antenna size by increasing the structure’s electrical length by meander structure and thus lowering its self-resonant frequency. Antenna was modelled with a FEM-simulator and it showed good performance: matching for global RFID UHF frequency and simulated gain was higher than for an ideal half-wavelength dipole. Matching and backscattering properties were verified by measurements and the results were compared against two commercial Gen2 short dipole -type tags. Both, matching and backscattering properties of the designed tag were found to be competent in this respect.

References