COMPARISON OF T-MATCHED AND DOUBLE T-MATCHED
SHORT DIPOLE TAG ANTENNAS FOR UHF RFID SYSTEMS

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Overview

• Introduction
• Analytical results
• Simulations & experimental work
• Conclusions
Introduction

- Widely used passive RFID tags do not include an energy source for the tag chip

- The tag antenna harvests energy from the incident carrier signal from the reader to power up the tag chip

→ Providing good complex conjugate matching between the antenna and the chip is a crucial design aspect

  – Computational electromagnetics is employed extensively in finding the optimal antenna geometry
Introduction

- This study concentrates on
  - Investigating how tolerances in antenna and chip impedances affect the power delivery from the antenna to the chip
  - Comparing the performance of T-matched and double T-matched short dipole tags
$P_{tag}$ is the power captured by the tag antenna

$P_{ic}$ is the delivered power to the chip

The power transmission coefficient is then given by

$$\tau = \frac{P_{ic}}{P_{tag}} = \frac{4R_a R_{ic}}{|Z_a + Z_{ic}|^2}$$

Due to the strong frequency dependence of the impedances, the frequency trend of $\tau$ dominates the frequency response of the tag.
Suppose that nominally the antenna and chip impedances are $Z_{a0} = R_{a0} + jX_{a0}$ and $Z_{ic0} = R_{ic0} + jX_{ic0}$, respectively.

Consider
- $p$ percentage tolerance in $R_{ic0}$
- $q$ percentage tolerance in $X_{ic0}$
- $r$ percentage tolerance in $R_{a0}$
- $s$ percentage tolerance in $X_{a0}$

What is the minimum power transmission coefficient under these deviations from the nominal values?

$$
\tau_{min} = \min_{\begin{align*}
Z_{ic} &\in \Lambda_{pq} \\
Z_{a} &\in \Lambda_{rs}
\end{align*}} \left\{ \frac{4R_{a}R_{ic}}{\left| Z_{a} + Z_{ic} \right|^2} \right\} \quad \text{(non-linear minimization problem of four variables)}
$$
Analytical Results
Minimum Power Transmission Coefficient

Key observations

• Contours of $\tau$ are circles in the source and load impedance planes
• Any rectangle can be enclosed in a circle
• $\tau$ is decreasing everywhere in directions away from the conjugate point
• The conjugate point is included in every contour circle

$\rightarrow$ The minimum value of $\tau$ in $\Lambda_{pq}$ is found at the corner touching the smallest circle that completely encloses $\Lambda_{pq}$
Analytical Results
Minimum Power Transmission Coefficient

• The same geometric interpretation holds in the antenna impedance plane ($\tau$ is symmetric w.r.t. subscripts "a" and "ic")

→ Solution to the minimization problem $\tau_{min} = \min \left\{ \frac{4R_a R_{ic}}{\left| Z_a + Z_{ic} \right|^2} \right\}$

is the value attained in one of the 16 corners of the 4-dimensional rectangle $\Lambda_{pq} \times \Lambda_{rs}$

→ Compared with a numerical search through a 4-dimensional grid, much less computations (only 16 evaluations of $\tau$) are needed
Simulations & Experimental Work

• The experimental work is to compares the performance of T-matching and double T-matching schemes for short dipole tag antennas

• The design uncertainty of each antenna is quantified with the developed impedance sensitivity analysis to guarantee judicious and fair comparison
Simulations & Experimental Work
Studied Tag Antennas

- On the left: T-matched quarter wave dipole
  - Inherent feature: monotonous reactance curve over the global UHF RFID frequencies
- On the right: double T-matched quarter wave dipole
  - Achievable feature: non-monotonous reactance curve over the global UHF RFID frequencies

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<th>$H = 15$</th>
<th>$T = 2$</th>
<th>$t = 1.5$</th>
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<td>T-Tag</td>
<td>$L_1 = 80.7$</td>
<td>$h_1 = 6.1$</td>
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- Both antennas are designed for Higgs-3 EPC Generation 2 UHF RFID IC by Alien Technology
Simulations & Experimental Work
Antenna and Chip Impedance

- Graphs below show
  1. Nominal antenna impedance
     - Simulated with HFSS
  2. Conjugate of the nominal chip impedance
     - Measured (Ref. [9] in the Proc.)

Enables the calculation of the nominal power transmission coefficient with lower bounds based on the expected impedance uncertainty.
Simulations & Experimental Work
Antenna and Chip Impedance

- Graphs below show the minimum power transmission coefficients
- Nominal case + three other scenarios:
  - One standard deviation uncertainty (Ref. [9] in the Proc.) for the chip impedance
    - Nominal antenna impedance
    - 5% and 10% antenna impedance tolerances
Simulations & Experimental Work
Measurements

• Measurements were conducted with Voantic Tagformance measurement device
  – A device for wireless characterization of RFID tags based on reader-tag communication

• Measured quantities
  – **Threshold power** ($P_{th}$), defined as the minimum transmitted carrier power sufficient to enable the tag under test to reply to the to EPC Gen 2 protocol’s *query* command
  – **Pathloss** ($L_{fwd}$) from the transmitter’s output port to the input port of a hypothetic isotropic antenna placed at the tag’s location
Simulations & Experimental Work
Measurement Results

- Comparison of the measured and simulated read range

**Measurements**: \[ d_{tag}^m = \frac{\lambda}{4\pi} \sqrt{\frac{1.64 \cdot P_{ERP}}{L_{fwd} P_{th}}} \]

**Simulations**: \[ d_{tag}^s = \frac{\lambda}{4\pi} \sqrt{\frac{\tau G_{fwd} \cdot 1.64 \cdot P_{ERP}}{P_{ic,0}}} \]

- Simulated tag antenna gain in the forward direction

- ICs read sensitivity: -18 dBm

- 2 W (in Europe)
Conclusions

• A method for efficient calculation of the exact lower bound of the power transmission coefficient
  → Rapid worst-case performance estimation for simulation based tag antenna designs

• T-matched and double T-matched short dipole tag designs were verified using the developed sensitivity analysis

• Both, measured and simulated results, clearly indicate how a minimal modification in the standard T-matching can yield a significant bandwidth improvement (double T-matching)
Thank you for your attention.