Application Note on RFID Simulations

Overview
Operating Principles
Inductive Coupling
Microwave Coupling
Coupling to Circuit Simulation
Customer Application
Summary

Franz Hirtenfelder/ CST GmbH
Overview

Radio Frequency IDentification

• Fundamental tool for Automatic Identification: authentication, ticketing, access control, supply management, parking, payment, vending, surveillance

• Advantages:
  - Contains more information than e.g. Barcodes
  - Can be read/write
  - Contactless ID (in contrast to phone or bank cards)
  - May become cheap mass product (e.g. in supermarkets)
General Principle

Typical characteristics of RFID:

- Tag is a passive device, energy is transmitted from reader
- Distance mm to 10m (typically ~20 cm)
- Contains silicon chip, can be read only or read/write
- Responds with modulated signal
- Mostly printed (planar) structures
## Frequencies

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>125/134 kHz</td>
<td>Animal identification, industrial applications, very robust, low data transmission (64 bit)</td>
</tr>
<tr>
<td>7.4 - 8.8 MHz</td>
<td>Electronic Article Surveillance (EAS)</td>
</tr>
<tr>
<td>13.56 MHz</td>
<td>“Smart Labels” widely used for product/article ID</td>
</tr>
<tr>
<td>868 - 928 MHz</td>
<td>Logistics,...</td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>Vehicle identification, electronic toll collection</td>
</tr>
<tr>
<td>5.8 GHz</td>
<td>Electronic toll collection in Europe</td>
</tr>
</tbody>
</table>
Operating Principles

• Inductive Coupling (125 kHz - 15 MHz)
  - Very small dimensions compared to l
  - Coupling only through magnetic field
  - Tag typically a planar coil

• Microwave Coupling (868 MHz - 5.8 GHz)
  - typically a regular antenna
    (e.g. planar folded dipole)
  - Matching network important to keep antenna small
Inductive Coupling

RFID tags are mostly planar coils with small dimensions compared to l

Hexahedral or tetrahedral F-Solver are typically most suited.

Simple Example for
13.56 MHz

At 13.56 MHz Measurement: (7.15 + 398i) W
Simulation: (7.0 + 395i) W

RLC parallel equivalent circuit fits broadband to simulation results

with courtesy and permission of Legic Identsystems AG
Reader & Tag
Inductive Coupling: 13.56 MHz

Complex Example for 13.56 MHz
Close-Up look at Reader-feeding
Close-Up look at Tag
Simulation of a realistic multi-tag / reader environment

- Design of Tag and Reader
- Microwave coupling (900 MHz)
- 3D EM Simulation with CST‘s „Complete Technology“ using Time-Domain and Frequency Domain solvers
- Coupling to circuit analysis with CST DESIGN STUDIO™
MicroWaveCoupling: TAG

SMALL FORM FACTOR TAGS

GEN 2 1X1

- Optimized for operation from 902 to 928 MHz
- Small form factor tag optimized for plastic packaging such as pharmaceutical pill bottles
- Near-field and far-field communication modes
- 25.4mm x 25.4mm

http://www.alientechnology.com/docs/Gen2_TagFam_datsht.pdf
S-Parameter

$|S_{11}|$ in dB, unmatched
Matching Network in DesignStudio™

Parameters to optimize

Goal definition
Surface-Current and Farfield f=900 MHz

Current Distribution before matching

Current Distribution after matching

phi-component

theta-component

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Parameter Study of a warped Tag

The impact on S-Parameters and farfields are investigated for warped tags. The conformal radius is varied in a range of 25 - 200 mm.
Parameter Study of a warped Tag

Farfield at 1.15 GHz

<table>
<thead>
<tr>
<th>Type</th>
<th>Farfield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximation</td>
<td>farfield (f \gg 1)</td>
</tr>
<tr>
<td>Monitor</td>
<td>farfield (f=1.15)</td>
</tr>
<tr>
<td>Component</td>
<td>aBS</td>
</tr>
<tr>
<td>Output</td>
<td>Directivity</td>
</tr>
<tr>
<td>Frequency</td>
<td>1.15</td>
</tr>
<tr>
<td>Radi. effic.</td>
<td>0.2567</td>
</tr>
<tr>
<td>Tl. effic.</td>
<td>0.1817</td>
</tr>
<tr>
<td>Dir.</td>
<td>1.529 dBi</td>
</tr>
</tbody>
</table>
Geometry of the Reader

A simple, vertically polarized patch-type reader antenna was used as reader antenna. The feed is designed as a simple coax-connector line.
Reader: Optimization

Parametric model setup

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>24.339</td>
</tr>
<tr>
<td>b</td>
<td>35</td>
</tr>
<tr>
<td>d</td>
<td>5</td>
</tr>
<tr>
<td>offset</td>
<td>4</td>
</tr>
</tbody>
</table>

Goal=S11 min at 900 MHz
Reader: Directivity

f=900 MHz

Theta-component

Phi-component

Type = Farfield
Approximation = enabled (kR >> 1)
Monitor = farfield (f=.9) [1]
Component = Abs
Output = Directivity
Frequency = 0.9
Rad. effic. = 0.9912
Tot. effic. = 0.9628
Dir. = 3.449 dBi
Tags on medical pill-boxes

For a more realistic scenario, an ensemble of tags were placed on the lids of a set of pill-boxes
Assembly

Tags and reader are positioned some distance apart and the S-parameters were computed.

Distance = 2000mm

CST MICROWAVE STUDIO®

- Advanced CAD modelling
  full parameterization
- Transient Analysis
  2.2h on 32bit machine, 400MB
- PBA + Subgrid
  Optimized runtime
S-Parameter

$|S|$ in dB

S-Parameter Magnitude in dB

Frequency / GHz

0.65 0.7 0.8 0.9 1.0 1.1 1.2 1.25

S1.5  S2.5  S3.5  S4.5  S5.5

www.cst.com
E-Field > e-field (f=900) MHz

Vertical view

Type = E-Field (peak)
Monitor = e-field (f=.9) I51
Component = Abs
Plane at y = 75.7
Frequency = 0.9
Phase = 67.5 degrees
Maximum-2d = 12624.8 V/m at 2080.7 / 75.7 / 45.72

Animated top view

CST - Computer Simulation Technology
Simulation of tags and reader

Broadband S-parameters are computed for a modified distance between Reader and Tag reduced to 250 mm. The reader is fed by an AM-signal, the deformed signal waveforms at the tag-ports can be observed.
Simulation of tags and reader

At 923 MHz the reader shows the best match. The HF-Signal for the AM-Generator is set to this frequency.
AM Signal Generator in DesignStudio
AM-Signal Generator + RF-IDs

HF-Signal

AM Input-Signal at RFID Reader-Antenna

AM Input-Signals at RFID Tag 1-4

Input-Signal

Ports 1-4
Generating the DC-Voltage at the tag

Tag-load (chip)

Matching network

Reader-Port

Tag Ports 2-5

Pin (nPin)

broadband 0-4 GHz
METRO Group & Checkpoint
Logistical Application

Side horizontal illumination
Towards minimum axis of the tag
Tags are between the boxes

Front horizontal illumination
Tags are between the boxes
Label Orientation and Detection

Illumination: Horizontal Front

Tag is embedded between the paper stacks with its axis along the axis of the paper stacks.
Label Orientation and Detection

Illumination: Vertical Front
Label Orientation and Detection
Illumination: Flat Side
Tag Design
Parameter Studies on Permittivity Variations

<table>
<thead>
<tr>
<th>Material</th>
<th>$\varepsilon_r_{\text{min}}$</th>
<th>$\varepsilon_r_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acryl</td>
<td>2,1</td>
<td>4,5</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>4,5</td>
<td>26,0</td>
</tr>
<tr>
<td>Aramid / Kevlar</td>
<td>1,6</td>
<td>4,0</td>
</tr>
<tr>
<td>Dacron / Polyester</td>
<td>2,8</td>
<td>8,1</td>
</tr>
<tr>
<td>Duroid / Teflon</td>
<td>2,0</td>
<td>6,2</td>
</tr>
<tr>
<td>Glass, soda lime</td>
<td>3,6</td>
<td>8,5</td>
</tr>
<tr>
<td>Nylon / Polyamide</td>
<td>2,8</td>
<td>11,0</td>
</tr>
<tr>
<td>Paper</td>
<td>2,0</td>
<td>6,0</td>
</tr>
<tr>
<td>Plexiglas - Polymethyl Methacrylate</td>
<td>2,8</td>
<td>11,0</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>2,7</td>
<td>3,5</td>
</tr>
<tr>
<td>Polyvinyl Chloride - PVC</td>
<td>2,3</td>
<td>12</td>
</tr>
<tr>
<td>Porcelain</td>
<td>4,4</td>
<td>11,0</td>
</tr>
<tr>
<td>Rubber</td>
<td>2,0</td>
<td>18,0</td>
</tr>
<tr>
<td>Water / distilled</td>
<td>77</td>
<td>87</td>
</tr>
<tr>
<td>Wood</td>
<td>1,2</td>
<td>8,5</td>
</tr>
</tbody>
</table>
Permittivity Variation

Tag on a cardboard, DIN A4 with 4mm thickness.

permittivity variation: 2..6
frequency shift: 200 MHz
Material Parameters and Volume

Simulated Scenario

label is on the middle of a dielectric volume of $1000 \text{ cm}^3 / 1 \text{ liter}$.

Permittivity ranges from $2 - 6$ (typical paper) in three steps.

1) The volume is a cubus of $100 \times 100 \times 100 \text{ mm}$.
2) The volume is a cardboard: $500 \times 500 \times 4 \text{ mm}$
3) The volume is a bar: $330 \times 60 \times 50 \text{ mm}$
Frequency shift for Cubus

Current at port in A

Frequency / MHz

www.cst.com
Frequency shift for a bar
330 x 60 x 50 mm
Frequency shift for a card board

500 x 500 x 4 mm

Current at port in A

Frequency / MHz
Summary

• CST RFID is a general concept using different technical principals

• complete technology approach offers best solution for each case
  - CST MWS Frequency Domain / CST EMS for inductive type
  - CST MWS Transient for microwave type

• Coupling between CST DS and CST MWS allows easy combination of circuit and 3D EM analysis, e.g. for
  - Tag matching networks
  - Reader circuits (using the new Transient solver in CST DS)