Predicting the influence of permittive materials on passive inductive coupled RFID-transponders

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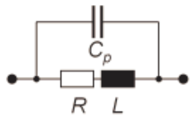
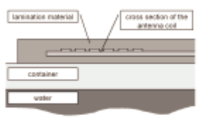
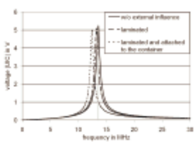


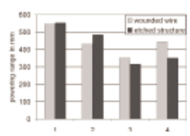
2. Set-up of the Test Scenario



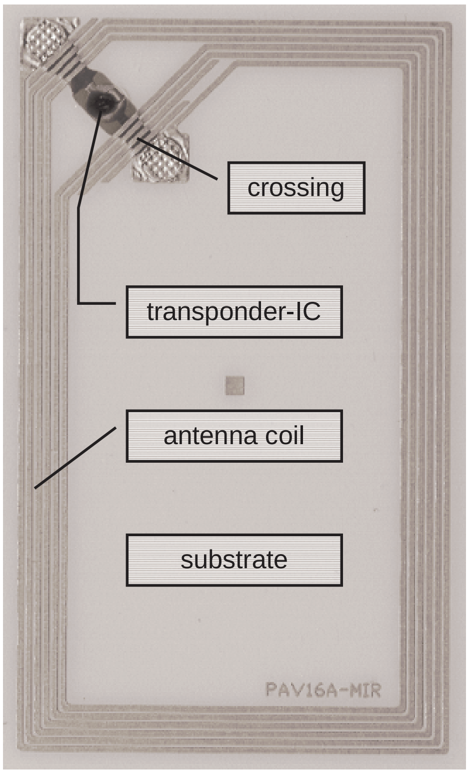
3. Influence of permittive Material on Antenna and Transponder



4. Effects on the Reading Performance

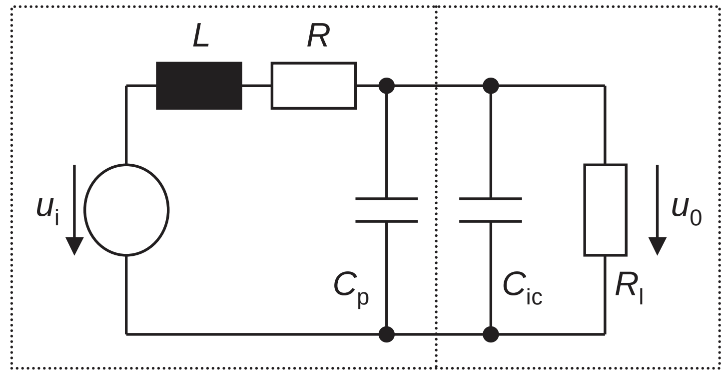


1. Modelling a planar RFID-Antenna Coil



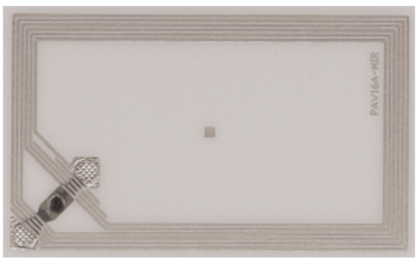
manufacturer: PAV Card

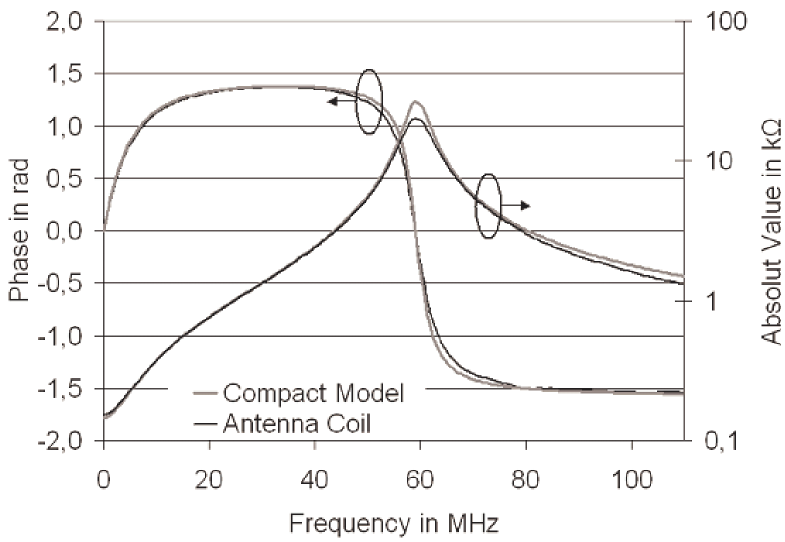
simple equivalent circuit



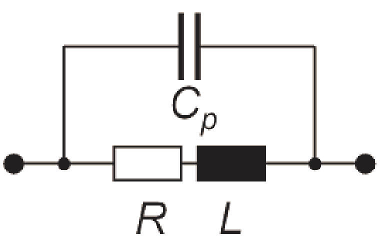
1. Modelling a planar RFID-Antenna Coil

- impedance of the antenna coil (measured)





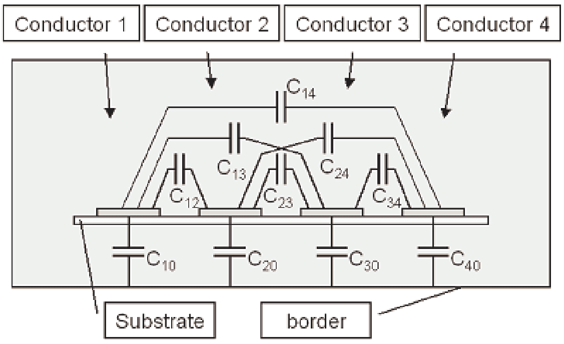
- derived compact model



- condition: quasi stationary state
  - size of the antenna coil is small in comparison to the wavelength
  - example: x_{coil} = 0.1 m vs. λ = 22.1 m (f = 13.56 MHz)

1. Modelling a planar RFID-Antenna Coil

- capacitance calculation of the cross-section (2D) by FEM-simulation



- calculation of the inductance by the method of partial inductances
  - development of the idea by A. Rühli in the 1970th
  - solving piecewise the integral:

$$L_{12} = \frac{\mu}{4\pi \cdot A_{L1} \cdot A_{L2}} \oint_{C_{L1}} \int_{A_{L1}} \oint_{C_{L2}} \int_{A_{L2}} \frac{1}{\mathbf{r}} \, dA_{L2} \cdot d\mathbf{s}_{L2} \cdot dA_{L1} \cdot d\mathbf{s}_{L1}$$

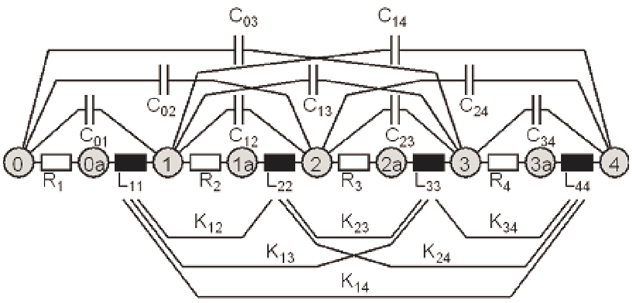
- resistance

$$R_{DC} = \rho \frac{l}{A}$$

  - if necessary skin- and proximity-effect can be considered ($\delta_{Cu,skin}$= 18 µm @ 13.56 MHz)

1. Modelling a planar RFID-Antenna Coil

- model with one node per turn for calculation of all parameters:



N	Inductances
N	Ohmic Resistors
(*N*²-*N*)/2	Coupling Factors
(*N*²+*N*)/2-1	Capacitances

- extraction of the parameter of the RLC-compact-model:
  - inductance and resistance

$$L = \sum_{\forall i=j} L_{ij} + \sum_{\forall i \neq j} M_{ij} \qquad R = \sum_{\forall i=j} R_{ij}$$

  - extraction of the 1st resonant frequency from the *PSpice*-simulation of the network
  - calculation of the parasitic capacitance C_p by

$$C_p = \frac{1}{(2\pi f_{res})^2 L + \frac{R^2}{L}}$$

- method is verified by hundreds of simulations and measurements
- model generation and parameter extraction is implemented in a software tool

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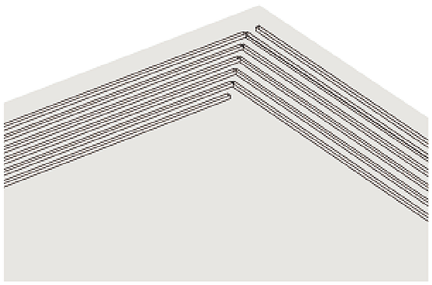
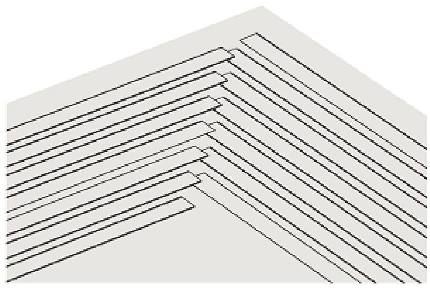
2. Set-up of the Test Scenario

- two different technologies are considered to examine the permittive environment:



wounded wire*)
(N = 6, $A_{cond.}$ = 90 x 90 µm², s = 300 µm)



etched structure
(N = 7, $A_{cond.}$ = 500 x 18 µm², s = 300 µm)

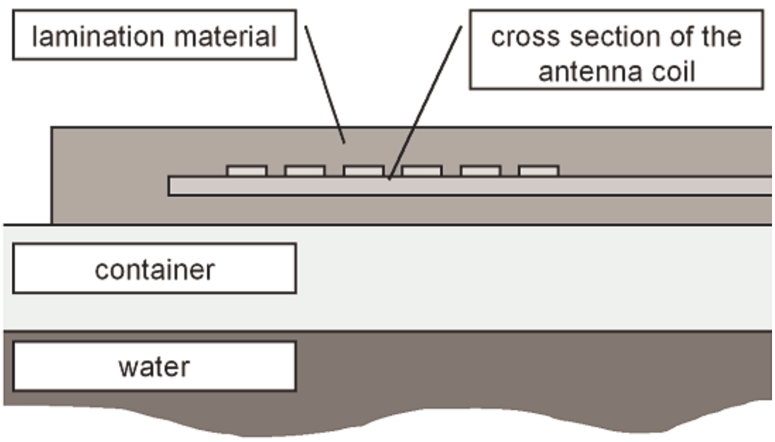
- parameter for both antenna coils:
  - conducting material: aluminium
  - substrate: PVC, 200 µm thick
  - coil area: A = 48 x 79 mm²
  - inductance: L = 7.1 µH
  - resistance: R = 4.8 Ω

*) approximated by a square shaped cross section

2. Set-up of the Test Scenario

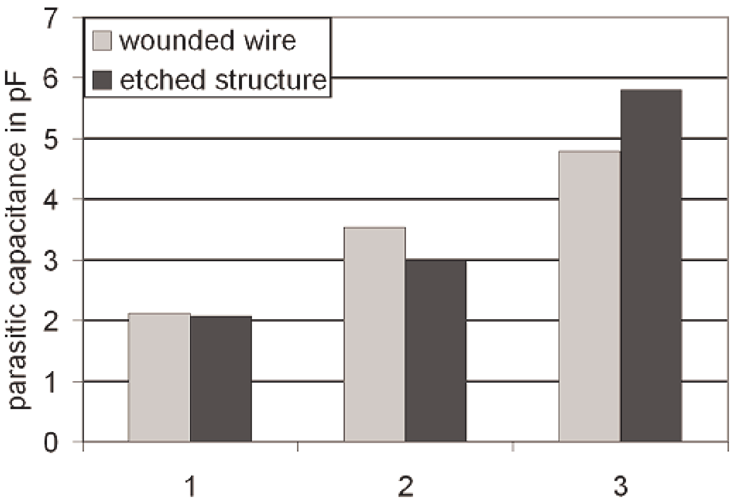
- environmental conditions:
  1. coil mounted on the PVC substrate, air in the surrounding
  2. lamination in PVC (overall thickness 0.76 mm)
  3. mounting on a water filled container (PVC, thickness of the wall 1 mm)

- material stack:



3. Influence of permittive Material on Antenna and Transponder

- inductance and resistance are not affected by the permittive material
- parasitic capacitance:
  1. antenna mounted on the substrate: capacitance approx. 2 pF
  2. antenna laminated: capacitance rises 67 % (wounded wire) and 44 % (etched structure)
  3. laminated antenna mounted on the water container: capacitance is up to nearly three times higher (etched structure)

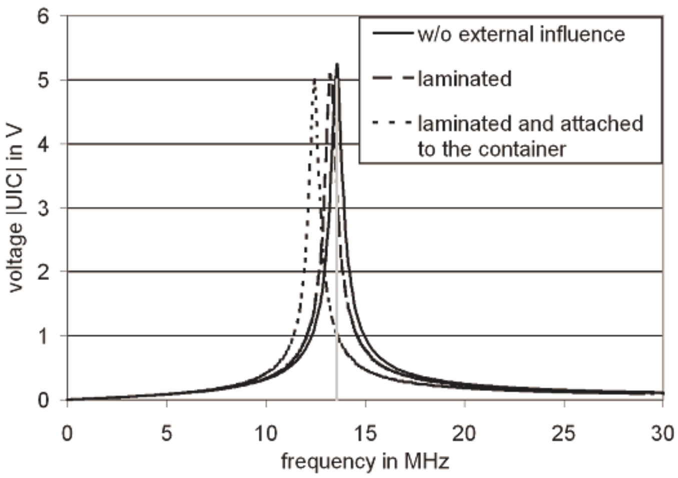


3. Influence of permittive Material on Antenna and Transponder

- Question: What are the consequences?
- Answer: Detuned resonant circuit and in the result a reduced reading range

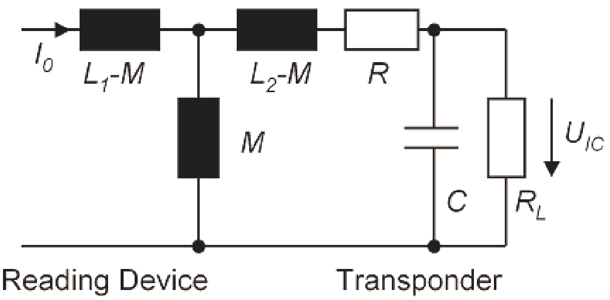
- needed resonance capacitance (L = 7.1 µH): $C_{total} = C_{IC} + C_p$ = 19.4 pF
  - $\Delta C_{p,max}$ = 3.7 pF (due to permittive environment)

- example: voltage at the transponder-IC for a fixed field strength (etched antenna)
  - $U_{IC,min} / U_{IC,max}$ ~ 0.2
  - $\Delta f_{res,max}$ = -1.1 MHz = - 8.4 %



4. Effects on the Reading Performance

- approach: calculation of the reading range via the coupling inductance *M*:



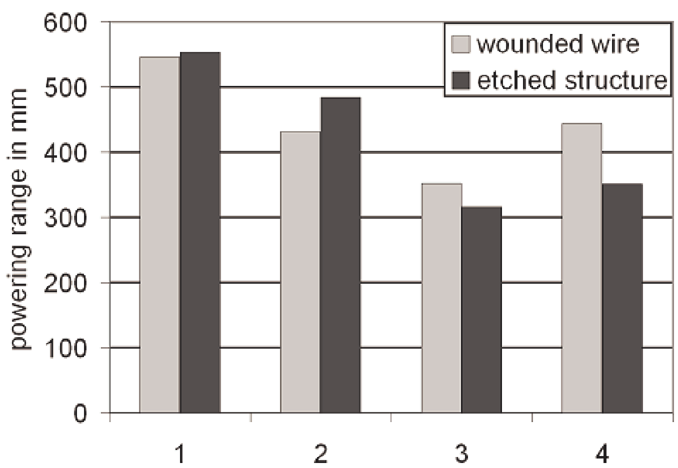
- calculation of U_{IC} (minimum operating voltage of the transponder-IC)

$$U_{IC} = \frac{\omega M \cdot I_1}{\sqrt{\left(\frac{\omega L_2}{R_L} + \omega RC\right)^2 + \left(1 - \omega^2 L_2 C + \frac{R}{R_L}\right)^2}}$$

- coupling inductance *M* is depending from the distance between the antennas
- assumptions for the following calculations:
  - reading antenna: *A* = 200 x 200 mm², *I* = 1 A
  - transponder-IC: R_l = 20 kΩ, $U_{IC,min}$ = 2 V
  - transponder resonant frequency: f_{res} = 13.56 MHz (for comparable results)
  - because no specific reading device is given, the powering range is calculated

4. Effects on the Reading Performance

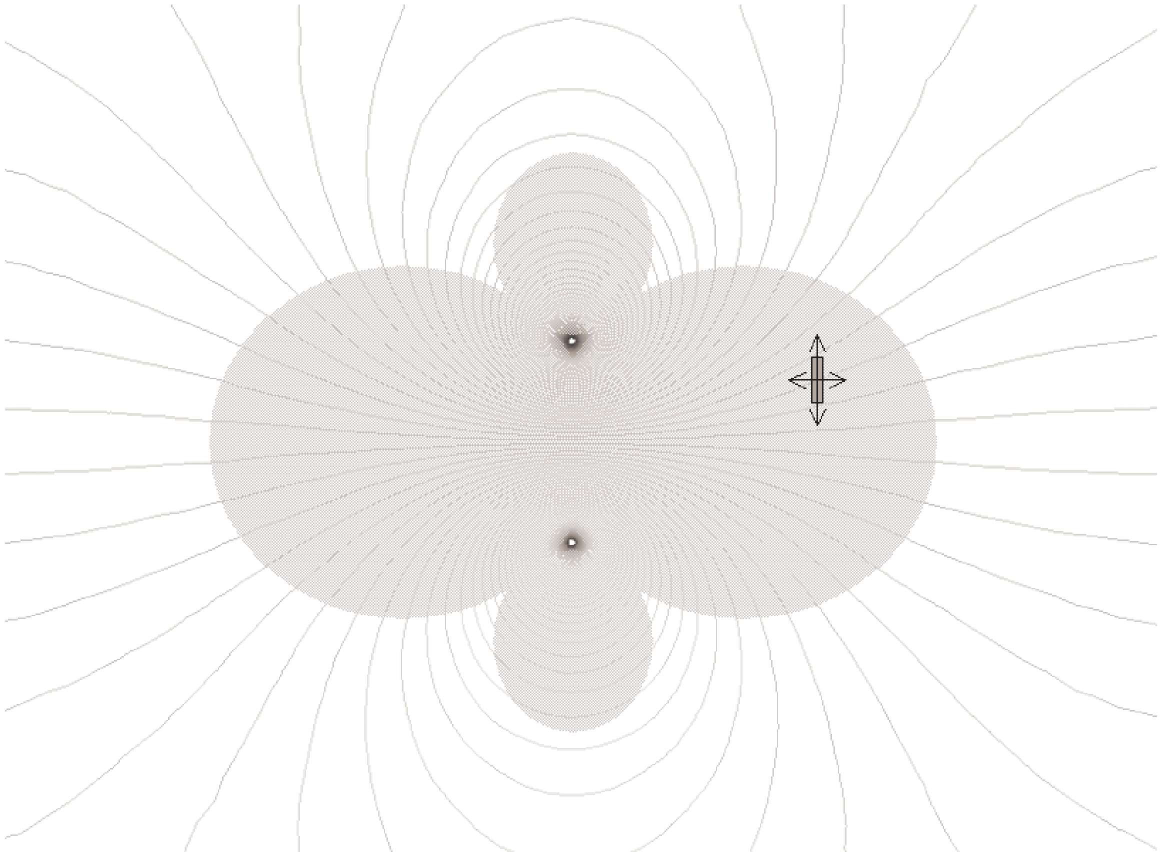
- results:
  1. antenna mounted on the substrate: nearly 550 mm powering range for both technologies
  2. antenna laminated: max. reduction of 21 % (wounded wire)
  3. laminated antenna mounted on the water container: max. reduction of 43 % (etched structure)
  4. laminated antenna mounted on the water container (tuned to 13.56 MHz after lamination): -19 % (wounded wire) vs. -37 % (etched structure)



Conclusion

- the presented modelling approach:
  - uses the compact model consisting of the elements:
    - resistance,
    - inductance,
    - parasitic capacitance,
  - allows to predict the electrical properties of the antenna coil up to the first self resonance,
  - is implemented in a software tool.
- permittive material in the surrounding of a planar antenna coil
  - results to a higher parasitic capacitance (nearly three times for the test set-up).
  - reading range is reduced due to detuning of the resonant frequency of the transponder.
- the compared manufacturing technologies show differences:
  - the wounded wire technology provides less sensitivity to permittive material
- antenna optimisation is required for applications in different environmental conditions
- careful set-up is necessary when performing measurements of the reading field:
  - the transponder may not mounted directly on plastic nor touched by hand
- further information: cichos@web.de

Thank you for your attention.



Cross section of the reading field of a transponder with horizontal axis in the surrounding of the reading antenna