

Characterization of Detuning Effects in Multilabel Scenarios

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Abstract. The continual growing field of applications for Contactless Smartcards and NFC (Nearfield Communications) leads to the occurrence of several close coupled labels in the operating field. This close coupling leads to additional physical effects, as a strong mutual interaction between labels results. It is topic of this work to characterize the physical behavior of such close coupled systems exemplary in terms of effected resonance frequency and seen voltage at the label. Mathematical methods as well as typical application scenarios based on simulation are pointed out, characterizing the influence on the performance.

Keywords: 13.56 MHz RFID Systems, close coupled systems, functionality

1 Introduction

The technology of Contactless Smartcards and NFC (Nearfield Communications) based on inductive coupling shows a wide spreading nowadays and will show a significant stronger dissemination in future [1]. Based on new application also the handling and characterization of several cards close together becomes more and more relevance. Mutual coupling based on high coupling factors between the investigated labels has an impact on the seen resonance frequency, quality factor, energy transfer, voltage at the IC and therefore on the overall performance. Therefore detailed physical understanding and modeling is indispensable for these applications.

Exemplary different application scenarios are pointed out, based on different parameters with the aim to advert to the complexity and diversity of possible scenarios. A pure analytical solution including all parameters does not exist until now but is topic of further research.

2 Basic Functionality of Passiv 13.56 MHz Systems

For inductive coupled passive systems the necessary energy is provided by the magnetic field of the reader [2]. The underlying antennas are represented by coils, which are linked via the magnetic field (\mathbf{B}) and the mutual inductance

(M) and/or the coupling factor (k). The mentioned physical values are given by the following elementary laws/equations [3]-[5]:

The law of Biot and Savart is given by

$$\mathbf{B} = \frac{\mu_0 \cdot i_1}{4\pi} \oint_S \frac{ds \times x}{|x|^3} \quad (1)$$

and allows the calculation of the magnetic field at every point as function of the current i_1 , as well as of geometry. In equation 1 μ_0 describes the permeability, x stands for the distance and s describes the integration-path along the coil.

Besides this the mutual inductance and the coupling factor, which is in general easier to handle, are given by

$$M = \int_{A_2} \frac{\mathbf{B}(i_1)}{i_1} dA_2 \quad (2)$$

$$k = \frac{M}{\sqrt{L_1 L_2}} \quad (3)$$

Here A_2 describes the area of the second coil, while L_1 and L_2 describe the inductance of the two coils.

Figure 1 depicts the very basic principle of an inductive coupled RFID system, which can be summarized as follows: due to the mutual inductance between first and second coil a change of the impedance on transponder side leads to an unequivocal change on the reader side (change of the seen impedance). This variation of the impedance on the secondary side, which is realized on the primary side is called load modulation - simply by loading the field more or less, information is transferred.

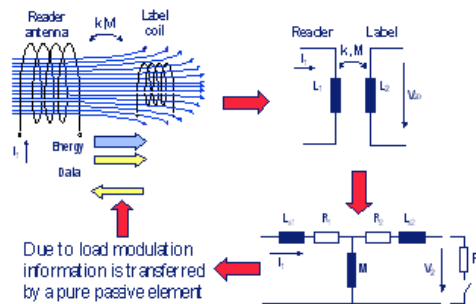


Fig. 1: Model of a tag/label.

3 Detuning-Impact on the Resonance Frequency

In [6], [7] a detailed mathematical modeling based on matrix analysis and eigenvalue-decomposition which includes the inductances and mutual inductances of the

investigated system was developed. This pure mathematical analysis allows to anticipate the behavior of the resonance frequencies very precisely - at least the lowest seen resonance frequency due to detuning. Nevertheless it is also stated that the analysis of all seen resonance frequencies except the lowest and dominant one is difficult, making an enhanced simulation setup necessary. Therefore simulation capabilities have been extended in this work with the aim to simulate typical application scenarios.

The underlying model of a typical label is shown in the following diagram and consists of the following elements:

L_1 , the inductance of the coil (antenna), C_1 , which includes a parasitic capacity of the coil itself as well as the capacity of the IC - together they build a resonant system tuned to 13.56 MHz or higher (note that real labels show a higher resonance frequency in general - this anticipates the prevention of detuning effects to some extent already compared to a system where cards and reader were tuned to 13.56 MHz). R_{L_1} describes a parasitic impedance and R_{C_1} stands for the impedance of the IC which is attached to the antenna. While the main focus of [6] and [7] was it to prove the correctness of the mathematical model and the concept of an eigenvalue analysis, it is aim here to point out different application scenarios in this paper, allude to the (possible) complexity of the setups.

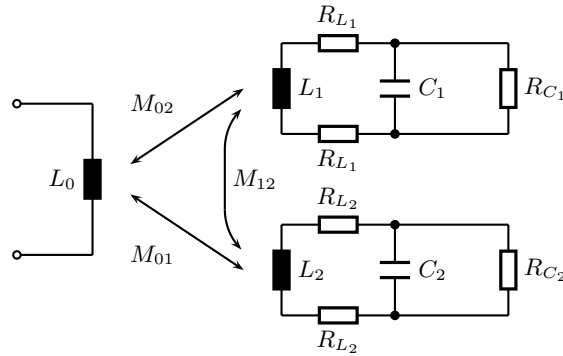


Fig. 2: Enhanced model of Reader and Card.

While the analysis of [6] is primarily focusing on two labels, the following diagrams point out the behavior of several labels exemplary - note that a pure analytical characterization becomes difficult and therefore exemplary results are essential to build an intuition.

The application scenario is that one or more cards are approaching the reader and as a parameter the seen resonance frequency is pointed out. For scenario I a third card (\mathcal{B}) is approaching cards (\mathcal{A}), (\mathcal{C}) and the reader (\mathcal{R}). The resonance frequencies have been chosen different, due to the fact that labels from different vendors are tuned to different frequencies. One can see that based on the corresponding model, significant shifts occur. Note that the number of resonance

frequencies always has to be equal to the number of labels/readers being investigated. The principal behavior can be anticipated by mathematical methods as shown in [6]. The differentiator is that here real application scenarios are pointed out as function of distance and label parameters. Scenario II describes that 3 cards are approaching a reader in parallel. Here it becomes obvious that the seen resonance frequencies are already defined by the coupling factor between the labels, the approximation to the reader device leads primarily to a change in amplitudes but no more change in frequencies.

The main statement of these investigations is that different applications may show a different behavior which might not be predicted but has an influence on the performance. Although the investigated models are still simplified to some extend, one can conclude that they provide a very good basis for further research, giving a physical intuition. A closed form of analysis and therefore prediction of all possible application scenarios is not possible at that point.

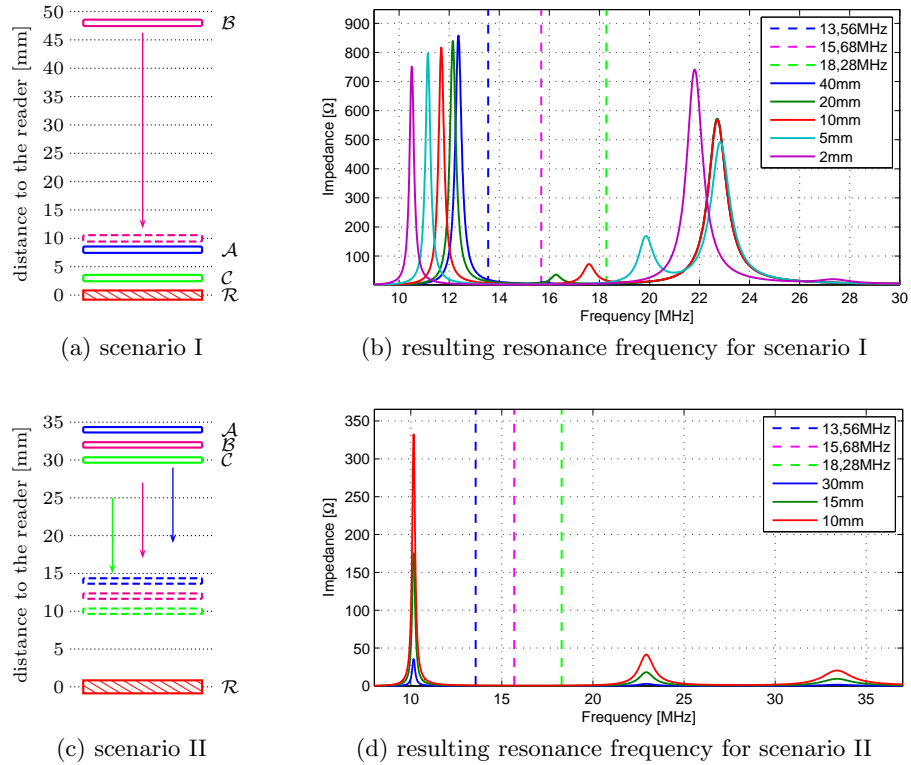


Fig. 3: Two application scenarios representing the different behavior in terms of resonance frequency.

4 Detuning-Impact on the Voltage

While the above models and derived results have the main aim to build a physical intuition of possible behavior and to point out the complexity, it is of significant relevance to enhance the model, enabling statements concerning further design parameters. One of these parameters is the seen voltage at the label. To enable this, the overall model is enhanced as follows.

The reader has been adapted to a typical topology as used also at ISO (ISO/IEC 10373-6) [8]. The model consists of the inductance L_R , a resistance R_{L_R} to tune the quality factor, as well as the capacities C_1 and C_2 to enable a power matching.

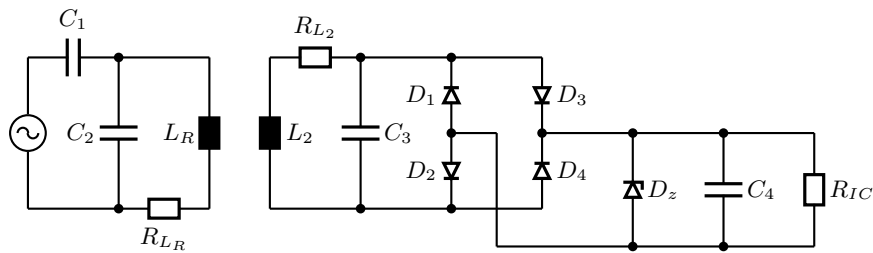


Fig. 4: Enhanced model of Reader and Card.

Based on the above model exemplary the voltage at the IC is pointed out, in the following diagrams. Two scenarios are investigated in detail: For both scenarios one label is placed in a distance of 10 mm to the reader, a second label is coming close to label one and reader. The simulations are based on a field-strength of 1.5 A/m (the calibration is carried out according to ISO/IEC 10373-6).

Scenario I describes the case that a label based on 13.56 MHz resonance frequency (label \mathcal{A}) is placed close to the reader while card two with a resonance of 14.2 MHz (label \mathcal{D}) is approaching the scenario. Due to the limiter functionality the voltage at label \mathcal{A} is almost constant as long label \mathcal{D} is further away. This changes significantly if the distance between the labels becomes low. For both cards the voltage is reduced due to detuning and has therefore an impact on the overall functionality.

Scenario II describes that label \mathcal{A} is adducted. A significant difference in the behavior can be seen there. The main interesting aspect is that the voltage at label \mathcal{A} achieves more voltage compared to label \mathcal{D} in a distance of about 2-15 mm relative to the label \mathcal{D} (note that this represents 12-25 mm distance relative to the reader). This means also that the label with bigger distance to the reader may experience a better energy supply than the label closer to the reader - a statement which is not intuitive. This statement also holds if two cards with

the same resonance frequency are used. Additional (theoretical) investigations are topic of further research.

5 Summary and outlook

It is topic of this paper to point out detuning effects in the context of multi label scenarios - scenarios which will appear much more often in future. Based on mathematical modeling the influence of a high coupling factor on the resonance frequency has been pointed out for two exemplary application scenarios – giving the basis for the development of a physical intuition.

Further more the effect of detuning on the seen voltage at the label has been characterized as function of underlying resonance frequency and relative distance to each other. Again the effect of detuning leads to mayor effects and impacts. The results being pointed out, lead to the final conclusion that significantly enhanced investigations in terms of modeling and mathematical analysis will have to be carried out in future.

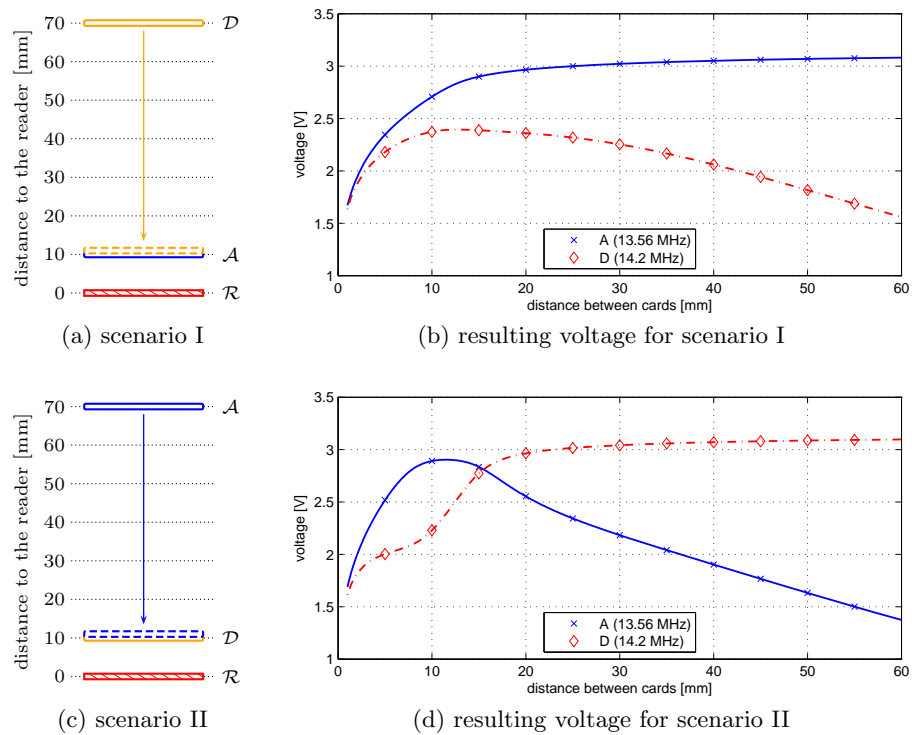


Fig. 5: Voltage at card due to different application scenarios.

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