Resonant Frequency Tuning for Multi-cards Applications in RFID Systems

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1. Introduction

A very simple and successful method is presented to determine the best resonant frequency for contactless smart cards. The RFID system we studied is made of one reader with a 50 ohms matched antenna at 13,56 MHz and two cards antennas to be tuned for communication optimisation. The simulations are performed with in inductively coupled transmission channel.

Emerging applications like ICAO e-passports need high data rates and long range communication. The problem of the presence of multiple visas inside the passport as not been resolved for the moment and any ISO standards describes the way to handle such multi-cards application. In this letter, multi-cards applications (antennas and integrated circuits stuck on the passports pages) are studied as shown on figure 1.

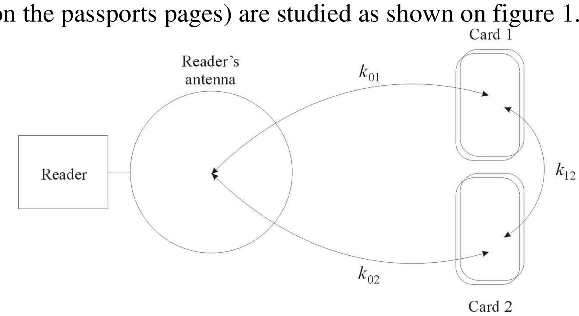

Figure 1 : Coupling coefficients between cards and reader's antennas

The reader's antenna is matched to 50 ohms. So, there is no reflected wave or loading effect at 13,56 MHz when there is no card in the field radiated by the reader. Reader sends energy (by the mean of an alternating magnetic field) to supply the two batteryless cards. To answer a request and further establish a communication with the reader, each card has an electronic switch (T_1 for card 1 and T_2 for card 2). The switch is placed in parallel with the integrated circuit and is driven by the embedded microcontroller [1, 2]. For both cards, we chose to switch capacitors as it has been proven that it induces higher modulation degrees than switching resistors [3]. Furthermore, the connected capacitors allow to tune or detune the resonant circuit formed with the reader. Depending on the state of T_1 and T_2, the quality factors of the cards change. The consequence is that the input impedance seen by the reader changes and the reader can demodulate the "backscattered" signal. Modulation degrees of these backscattered signals are strongly influenced by two critical points. First of all, space position of the cards directly affects the coupling coefficients (k_{01}, k_{02} and k_{12} on figure 1) between cards and reader. Secondly, the resonant frequency of each card affects the whole system, including the backscattered signal of the other card. In the same time the telesupply voltage of both cards is affected. This letter proposes a very simple method, based on simulations with Advanced Design System software, to achieve the best modulation degrees of the backscattered signals for a given minimum telesupply voltage of the chips. The best compromise between these two parameters is then reached.

2. Coupling Coefficients

The value of the coupling coefficient is very important in order to derive the coupled equations and to find the actual best switched loads. By connecting a two ports vector network analyser between reader's antenna and the card's antenna, it has been shown [4] that the measured S-Parameters can easily help on finding the right coupling coefficient k. With a method derived from [4], reflection and transmission S-Parameters for a two cards application are measured so we can infer the values of the three coupling coefficients : k_{01}, k_{02} and k_{12} (figure 1). Figure 2 shows the equivalent electrical schematics for two contactless smart cards simulations.

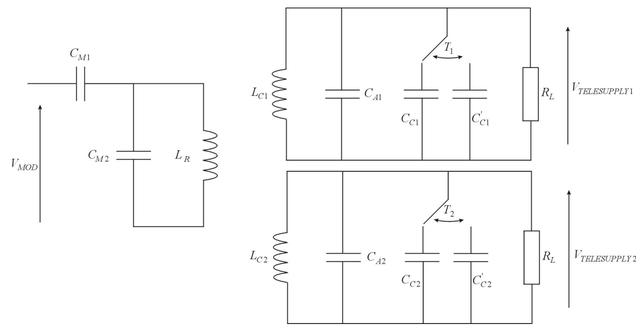

Figure 2 : Electrical equivalent model for simulations

3. Case of a unique resonant frequency for both cards

In this first study, C'_{C1} and C'_{C2} on figure 2 are not used so that C_{C1} and C_{C2} are connected or not depending on the T_1 and T_2 states. C_{A1} and C_{A2} are two capacitors forming a resonant circuit with the inductors L_{C1} and L_{C2} at a frequency to be determined. In that case, the resonant frequency the cards is the same when the card communicates with the reader or not. When only one card is present in the radiated field, the chosen resonant frequency is of course 13,56 MHz in order to optimize the energy transfer between the reader and the contactless card. Otherwise, in almost all multi-cards applications where switched loads are purely resistive, resonant frequencies of the cards are chosen higher than 13,56 MHz. Unfortunately, the determination of the resonant frequencies is empirical. In our study, C_{C1} and C_{C2} represent the switched capacitive loads and T_1 and T_2 are single position switches. Finally, R_L is the equivalent input impedance of the embedded chip. On the reader side, C_{M1} and C_{M2} insure the matching impedance of the reader antenna to 50 Ohms at 13,56 MHz [5]. The ISO/IEC 14443 and ISO/IEC 15693 standards predict that when more than one card communicates with the reader at the same time, a collision is detected. An anti-collision protocol (deterministic or probabilistic) insures that only one card is selected by the reader and can communicate with it. All the other cards are put in an IDLE state. In our study, we choose to follow the standards recommendation and then consider the modulation degree induced by the communication between one card and the reader when the other card is in an IDLE state. Nevertheless, even in the IDLE state, the presence of other cards in the reader's radiated magnetic field induces variations of the coupling coefficients and shifts the overall resonant frequencies. In order to compensate this phenomenon, C_{A1} and C_{A2} must form a resonant circuit with the antennas at a frequency F_R which is no more 13,56 MHz. $C_{A1,2}$ values are derived using the simple equation :

$$C_{A1,2} = \frac{1}{(2\pi F_R)^2 L_{C1,2}} \tag{1}$$

The aim of this section is to determine the best values of C_{C1} and C_{C2} and the best resonant frequency F_R to achieve the best modulation degrees of the backscattered signals with the constraint to always have a minimum telesupply voltage in order to power the embedded chips. By switching C_{C1} and C_{C2}, the input impedance of the system is changed. So is the voltage (V_{MOD}) probed at the reader's antenna (figure 2)

The Modulation degrees of the backscattered signals are given by the following equation:

$$MOD_{1,2} = \frac{Max(V_{MOD1,2}) - Min(V_{MOD1,2})}{Max(V_{MOD1,2}) + Min(V_{MOD1,2})} \tag{2}$$

Of course, $Max(V_{MOD1})$ and $Max(V_{MOD2})$ are reached when C_{C1} and C_{C2} are disconnected. To obtain the curves shown on figure 3 and the associated resonant frequency for maximum modulation degree, we execute the following steps : When card number 1 or 2 is communicating, its telesupply voltage ($V_{TELESUPPLY\,1,2}$) must be higher than a minimum value (here we fix this minimum to 3V for numerical applications). For a frequency between 11 MHz and 25 MHz, $C_{C1,2}$ are swept and when $V_{TELESUPPLY1,2} > 3V$, we search the minimum of $V_{MOD1,2}$ ($Min(V_{MOD1,2})$). The best resonant frequency of the cards is the frequency for which one $MOD_{1,2}$ reaches its maximum. C_{C1} and C_{C2} are the capacitances corresponding to this particular frequency.

Figure 3 shows the maximum modulation degrees of the backscattered signals induced by the cards, when C_{C1}, C_{C2}, C_{A1} and C_{A2} are correctly chosen.

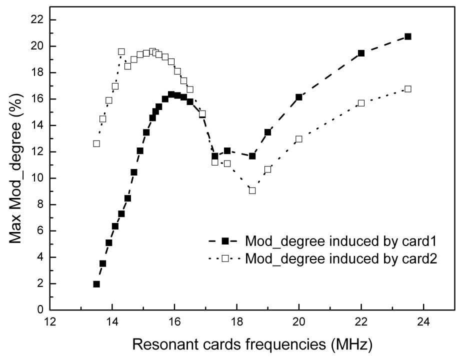

Figure 3 : Maximum modulation degree with cards accorded to the same frequency

4. The double switched capacitors approach

In this part, we proposed to use two other capacitors, C'_{C1} and C'_{C2} as shown on figure 2. Cards number 1 and 2 are accorded to two different resonant frequencies F_{R1} and F_{R2} depending on C_{A1} and C_{A2} whether the card is communicating with the reader or not. If the card number 1 communicates with the reader, only C_{A2} is connected on card number 2. The two positions switch of card number 1 connects in parallel to C_{A1}, either C_{C1} or C'_{C1}. The resonant frequency of the non communicating card influences the coupling between antennas in the system and modifies the modulation degree of the backscattered signal induced by the communicating card. To derive this modulation degree, we used the following steps : For each resonant frequency of card number 1 between 11 MHz and 25 MHz, C'_{C2} is disconnected and C_{C2} is swept. When $V_{TELESUPPLY2} > 3V$, we search the minimum of V_{MOD2}. C_{C2} is then disconnected and now, the value of C'_{C2} is swept. When $V_{TELESUPPLY\,2} > 3V$ we search the maximum of V_{MOD2}. By replacing 1 by 2 and 2 by 1 in the previous algorithm, resonant frequencies of both cards are determined and C_{A1}, C_{A2}, C_{C1}, C'_{C1}, C_{C2} and C'_{C2} are chosen to reach the best modulation degrees of the backscattered signals. Figure 4 shows the maximum modulation degree that it is possible to achieve with our proposed method.

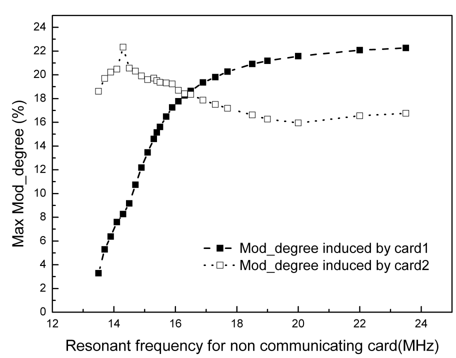

Figure 4 : Maximum modulation degree in the case of card depending resonant frequencies (communication with the reader or IDLE state)

5. Results

Actually, RF designers accord all the cards antennas at the same frequency. In order to take into account the modification of the inductive coupling due to the presence of multiple cards in the reader's radiates field, this frequency is greater than 13,56 MHz. The first method presented in this letter allows to precisely determining the best same resonant frequency for all the cards. This method does not lead to the best possible modulation degree but the result is that there is no difference in the switch position wether the card communicates with the reader or not. This leads to a very simple architecture of the embedded chip very near to that we can find in present smartcards.

The results of the second study can be applied when the cards positions are well known (coupling coefficients fixed). A typical application is the ICAO e-passports and visas. Table 1 summarises the best modulation degrees we can achieve with these two studies. The method described in the second study can be used for restricted applications but considerably improves the RFID systems in terms of distances and/or data rates. In the new contactless card's architecture of figure 2, the two cards are different (ie the values of the capacitors are not the same and the resonant frequency depends on the fact that the card communicates with the reader or not). This can be of course a disadvantage for chips manufacturers and card's cost. A good alternative to this problem is to design the same chip with several parallel capacitors. By programming the cards, it is possible to switch a predetermined number of capacitors to obtain the desired value.

Table 1 : Maximum Modulation degrees for the two proposed studies

	Modulation degree		Resonant frequency	
	Card number 1	Card number 2	Card number 1	Card number 2
First study (one resonant frequency for all cards)	16%	19%	15,9 MHz	15,9 MHz
Second study (two different resonant frequencies)	22%	22%	23,5 MHz	14,3 MHz

6. Conclusion

This letter proposes new methods that considerably increase the modulation degrees of the backscattered signals in multi-cards applications for RFID Systems. The design of figure 2 with the use of multiple capacitors switched with multiple positions switches, suits completely to the enquiries of the market in terms of electronic passports.

7. References

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