From Power to Performance in 13.56 MHz Contactless Credit Card Technology

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Abstract—**Contactless Credit Cards as a sub-division of Smart Cards offer a promising new market for RFID technologies. We consider in simulations, verified with experimental results, the way from the electrical supply power as required for the operation of Contactless Payment Terminals to the Card performance as required to allow a payment transaction within a limited time. For this purpose, we consider the PayPass Reference equipment, which is similar to a typical use case and specified to test product compliance.**

I. Introduction

Contactless Credit Cards allow comfortable handling in the payment procedure and offer all security mechanisms of conventional Credit Cards. A volume of 40 million such Cards is already in the field in the USA to date and market introduction for Europe is starting. A technical expert group at MasterCard has worked out the so-called PayPass specifications and has defined specific test equipment and test methods based upon the standard for Contactless Proximity Cards ISO/IEC 14443, which were adopted by the EMVCo LLC consortium [1]. This organization, founded 1999 by Europay, MasterCard and Visa is now operated by JCB, MasterCard and Visa and provides specifications for physical and lower layers to allow a common infrastructure for Contactless Credit Cards. Applications and performance requirements are specified on top of this by each individual Credit Card company. In this paper, we consider energy aspects from Terminal to Card based on the EMVCo specifications.

II. H-Field in Reference PCD Operating Volume

Methods for testing Contactless Credit Cards for functionality on physical level are specified in [2]. The approach was to specify a test equipment, which comes as close as possible to the real application case. For this reason, Cards are tested in the Operating Volume of a so-called Reference PCD (proximity coupling device), which in principle is a Terminal antenna including the matching network, to be connected via coaxial cables to a set-up of laboratory instruments (amplifier, waveform generator,…). Terminals, on the other hand, are tested using a so-called Reference PICC (proximity integrated chip card), which contains antenna and analogue front-end of a typical Contactless Card and so emulates its physical properties. Both devices are specified in detail, including layout, component assembly and calibration procedure. Table 1 gives a list of parameters for the Reference PCD.

TABLE I. Some properties for the PayPass Reference PCD antenna as used for simulation.

PCD antenna radius a	32.5 mm
Offset distance to Landing Plane	19 mm
(self-) Inductance L_{TX}	756 nH
Q-factor Q_{TX}	~ 40
Number of turns N_{TX}	2
Total loop current I_{TX} (for "Nominal Field" condition)	1.38 A(rms)
PCD antenna impedance (at 13.56 MHz) Z_{TX}	50 Ω

The reference PCD consists of an electrically compensated loop antenna of 65 mm average diameter. The Operating Volume, the spatial region in which the Card function is tested, is specified as a cylinder above the "Landing Plane", in about 19 mm offset to the loop antenna. In this volume, the Card or object center is varied in planes parallel to the PCD antenna. Fig. 2 shows the shape of the Operating Volume including the specified dimensions.

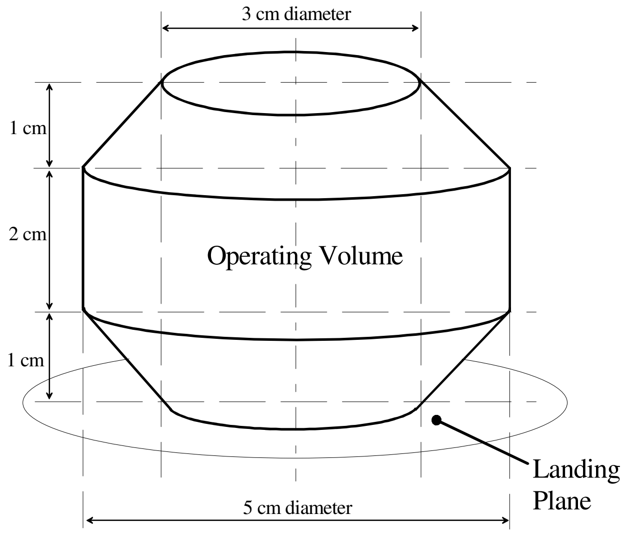

Figure 1. Operating Volume according to [2].

The H-field emitted by the Reference PCD antenna can be simulated using the Biot-Savart law, which allows an analytical calculation using a mathematical software. This gives a first-order approximation, which already shows a satisfactory fit to measurement results, although more exact results could be gained using a field simulator and the real antenna geometry. In this calculation the total antenna current (consisting of real and blind component) is considered as the sum over all turns at the average transmit antenna diameter. This alternating current at 13.56 MHz is the root cause for the H-field. We consider the z-component of the H-field, which is perpendicular to the plane of the PCD transmit antenna and to the Card antenna.

$$r_{SR}(\Phi, x_R, y_R, z_R)^2 = (x_S + a \cdot \cos(\Phi) - x_R)^2 + (y_S + a \cdot \sin(\Phi) - y_R)^2 + (z_S - z_R)^2 \qquad (1)$$

$$H_z(x_R, y_R, z_R) = \frac{I_{TX} \cdot a}{4 \cdot \pi} \cdot \int_0^{2\pi} \left\{ \frac{e^{-i \cdot \beta \cdot r_{SR}}}{r_{SR}^2} \cdot \left(i \cdot \beta + \frac{1}{r_{SR}} \right) \cdot \left[a + (x_S - x_R) \cdot \cos(\Phi) + (y_S - y_R) \cdot \sin(\Phi) \right] \right\} d\Phi \qquad (2)$$

The distance between a point on the PCD antenna circumference (PCD center at coordinates x_S, y_S, z_S) and any receive point in space (at coordinates x_R, y_R, z_R) for the PCD antenna radius a is given by (1). Equation 2 allows to calculate the H-field component perpendicular to the Card antenna, using cylindrical coordinates for the circular PCD antenna. β represents the phase constant.

$$\beta = \frac{2\,\pi\, f_C}{c} = \frac{2\,\pi\, 13.56 \cdot 10^6\, Hz}{3 \cdot 10^8\, m/s} \qquad (3)$$

Neglecting any PCD antenna detuning or Loading effect due to the Card antenna resonance circuit, the output power into the 50 Ohm PCD antenna load (at 13.56 MHz) to achieve the Nominal Field strength can be calculated by (4).

$$P_O = \frac{I_{TX}^{\;2} \cdot \omega \cdot L_{TX}}{N_{TX}^{\;2} \cdot Q_{TX}} \qquad (4)$$

For the values given in tab. 1, an output power of 0.767 W can be calculated. This gives a minimum requirement for the Lab amplifier, which in practice should have at least 3 W to allow measurements for Nominal Field condition with sufficient margin to any compression effect. The driver current can be calculated by (5),

$$I_D = \sqrt{P_o / Z_{TX}} \qquad (5)$$

which in this case gives 124 mA (root mean square), and the diver voltage, which can also be easily measured with a scope probe is given by (6),

$$U_D = 2\sqrt{2} \cdot \sqrt{P_0 \cdot Z_{TX}} \qquad (6)$$

which gives 17.51 Volts (peak to peak).

Evaluating the absolute value of the integral formula for a cross-section over the PCD antenna in the Operating Volume at three different distances to the Landing Plane gives the H-field strength in space, as shown in fig. 2.

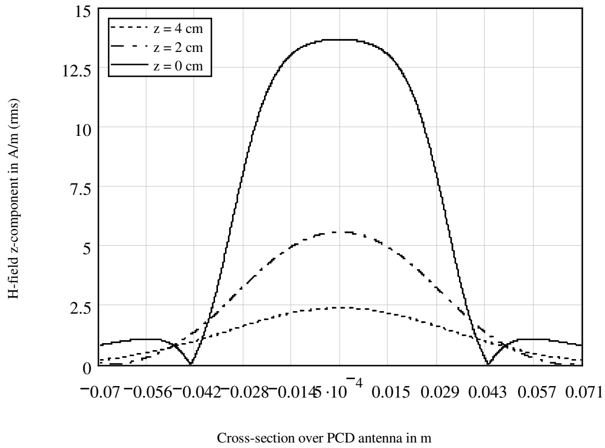

Figure 2. H_z-field over PCD antenna cross-section in distance z = 0, 2, 4 cm (in the Operating Volume).

III. CARD EMBOSSING

The typical format of Credit Cards, like for all Cards is specified in ISO/IEC 7810. The so-called ID-1 Card is 85.5 mm long, 54 mm wide and has a thickness of 0.76 mm. According to this size, also the typical antenna area for Contactless Smart Cards has a certain format, which was specified as Class 1 PICC antenna in [3]. Such a printed coil antenna consists of 4 turns of an outer size of 72 x 42 mm. Most of the Contactless Cards which are in practical use, and also the antenna of the Reference PICC are compliant to this format. Chip parameters specified on system level in the ISO/IEC 14443 product standard are verified with reference to a Class 1 antenna.

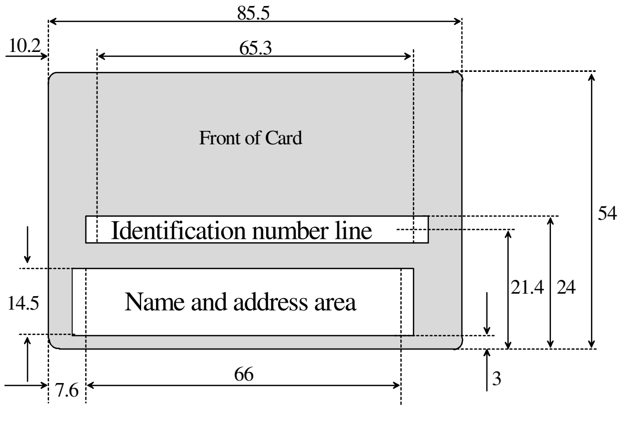

Figure 3. Area for Embossing, simplified according to [4] (typical values in mm).

However, Credit Cards use another feature, embossed characters are applied in an area specified in ISO/IEC 7811. This means, letters or numbers are raised in relief at the front side of the Card by a thermal imprinting process, which deforms the Card material, typically PVC or PVCA. The Card antenna cannot be placed in the embossing area, as it would be destroyed by the heat and pressure of the embossing process. The area specified for embossing partly covers the area which is used for Class 1

Card antennas as shown in fig. 2, so it would be a challenge for the accuracy of the Card antenna production and the embossing process to fabricate a Class 1 antenna. For this reason, practically all Contactless Credit Cards in the field use smaller antenna areas to remain outside of the restricted area.

IV. SMALL CARD ANTENNA PROPERTIES

The functional properties of the Transponder at the air interface depend much on the antenna. For this reason, several proposals were made to classify smaller Card antennas, similar to Class 1. As the remaining area has approximately half the size of the Class 1 antenna, it is sometimes referred as "half-size antenna" among development engineers. A specification for such an antenna was proposed in [5], where it is named Class 2 antenna. For a quarter of the Card size, a Class 4 antenna was specified in an equal way. We will follow this denomination and specification in this contribution. Parameters for these Card antenna classes are given in tab. 2 and the antenna area is shown in fig. 4.

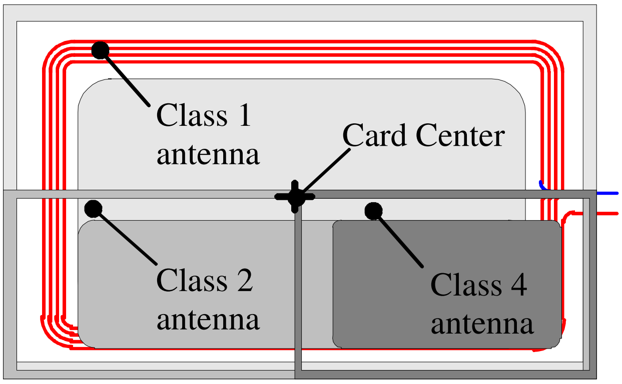

Figure 4. Card antenna areas for Class 1, 2 and 4 (Class 1 antenna shown).

TABLE II. PARAMETERS FOR SMALLER PICC ANTENNA CLASSES [5].

PICC antenna	**Class 1**	**Class 2**	**Class 4**
total area (l x w in mm)	72 x 42	72 x 21	36 x 21
turns N_{RX}	4	6	9
inductance L_{RX}	2.31 µH	3.42 µH	3.65 µH
serial resistance R_S	0.85 Ω	1.58 Ω	1.64 Ω
parallel capacitance	5.5 pF	5.22 pF	3.65 pF
Conversion factor: Chip current per H-field strength	4.7 mA (DC) per A/m (rms)	2.76 mA (DC) per A/m	1.02 mA (DC) per A/m (rms)

Measurements were made using a Reference PICC as specified in ISO/IEC 10373-6, which consists of a Card antenna and a parallel capacitor to build a parallel resonance circuit (tuned to 13.56 MHz in this case), a full-wave rectifier and a variable shunt resistor with buffer capacitor on the DC side.

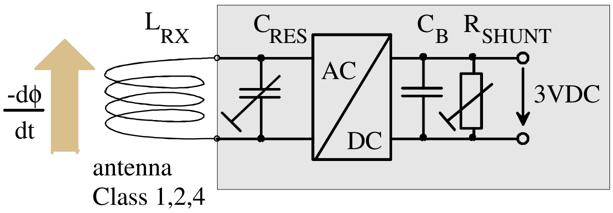

Figure 5. Reference PICC principle schematics.

For antenna class 1, 2 and 4 the Reference PICC was placed at the center positions and at the outer border positions (representing the worst case) of the Operating Volume. The PCD antenna was emitting the Nominal Field strength. For each position of the Reference PICC the variable shunt resistor was adjusted in this way, that 3 Volts DC could be measured across the resistor. Then the Reference PICC was taken out of the H-field, the resistor value was measured (allowing to calculate the current according to the law of Ohm). Then the Reference PICC was placed in a homogenous H-field and the field strength was adjusted so that again 3 Volts DC could be measured across the shunt resistor. In this way, the according average H-field, as picked up by the specific antenna Class for the specific position in the Operating field could be determined. The resulting values then were sorted over the average H-field strength for each class. Figure 6 shows the resulting relation between available chip current and average H-field.

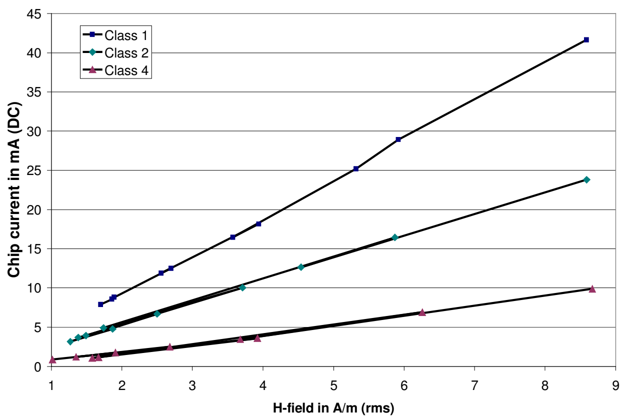

Figure 6. Available Chip current measured for different Antenna Classes in Operating Volume.

As can be seen, the relation is nearly linear, which allows to give a conversion factor for every Card antenna area between average H-field and available chip current. These factors are given in tab. 2. So the Card antenna resonance circuitry acts like a current source for the chip, which of course only is valid, if the induced voltage allows to exceed 3 Volts after the rectifier. For Class 4, this condition was already violated at two points of lowest average H-field in the Operating Volume.

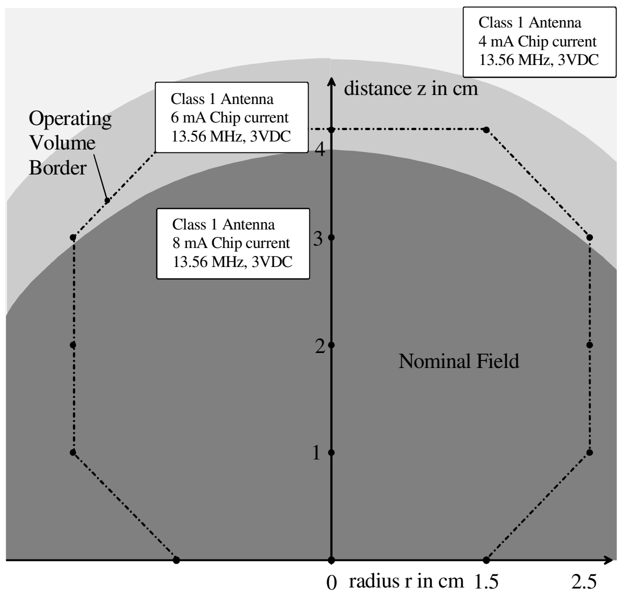

Figure 7. Available chip current for Class 1 antenna.

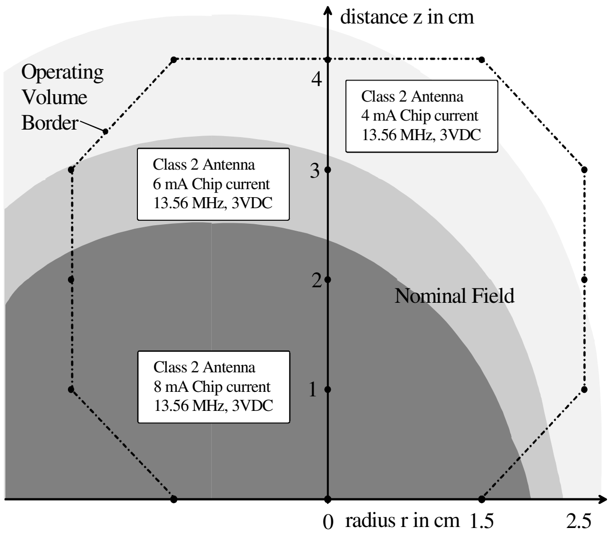

Figure 8. Available chip current for Class 2 antenna.

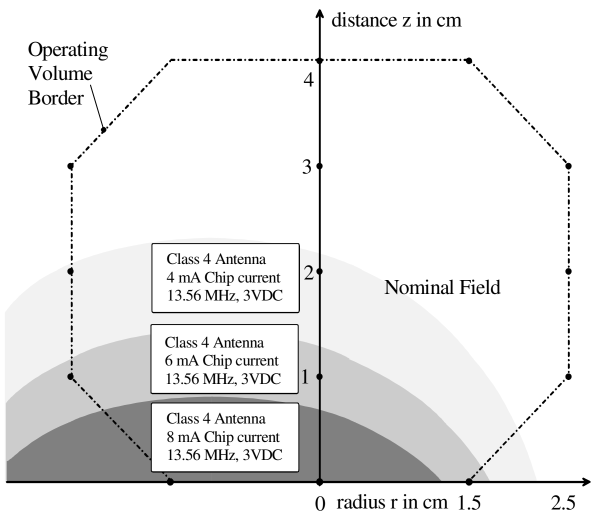

Figure 9. Available chip current for Class 4 antenna.

Based upon this knowledge, it is possible to simulate the available chip current for different antenna classes. As the Card antenna picks up an equivalent average H-field, averaged over the antenna area, equation 2 was evaluated for a grid of 9 x 13 points in the area of each antenna Class. The Card center point (with antenna Class 2 asymmetric on one half side, and Class 4 asymmetric for width and length) was varied to different positions in the Operating Volume. Figures 7, 8 and 9 show the border lines for available chip current for the Card antenna Classes in the Operating Volume under Nominal field conditions, and for 13.56 MHz Card resonance frequency and 3 VDC chip internal supply voltage.

For a Class 1 antenna, the available current distribution in the Operating Volume is symmetrical, and the current is exceeding 6 mA for the mentioned conditions and even more than 8 mA are available for most of the volume. Taking into account an internal supply voltage of 3 V, this means more than 20 mW supply power are available for chip operation, and the Card Q-factor in operation is lower than 4. For a Class 2 antenna, the H-field and the available current are asymmetrical, resulting in only about 3.6 mA available current on one side of the Operating Volume. The Class 4 antenna position in the Card also causes this asymmetry, and the range between maximum and minimum available current in the Operating Volume is very high. As the voltage drops below the 3 Volts on the upper right border, the current drops to 0 for the specified conditions. The range of average H-field strength and available chip current for antenna Class 1, 2 and 4 in the Operating Volume is shown in fig. 10.

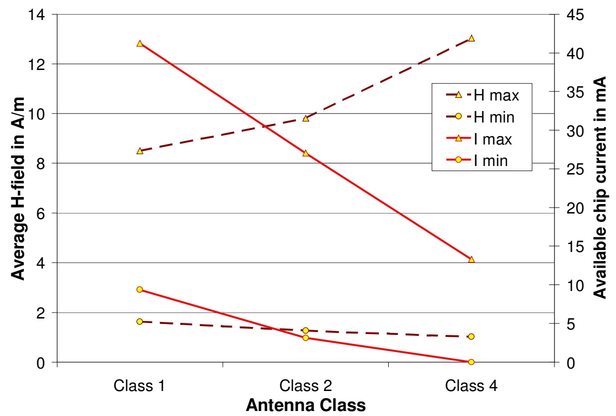

Figure 10. Range for average H-field and available chip current in the Operating Volume for antenna Classes.

V. Performance in Credit Card Application

Performance requirements are specified only as a certain time for a defined transaction application, as for the user of Contactless Credit Cards, considerations of available power and chip current are not relevant. As an overall benchmark it is known, that an operation time below 300…800 ms is not recognized as delay by the user. This psychological time value has to be met by the Card and the Terminal to complete a transaction. The higher application layers are specified in detail separately by each Credit Card company. We will consider the relation from chip current to application time in principle, but stay general, as the specification phase is not completed yet and details for specific chips are usually confidential information.

A chip for Smart Card applications consists of different blocks, there are

- units to perform the specified function,
- sensors and chip protection mechanisms,
- chip security functions,

which all consume current.

Seen from the time perspective, for a given application there are contributions of fixed time like read/write memory access or the communication phase according to the protocol, and there are contributions depending on available current, e.g. calculations depending on the processor clock, which may be switched to different frequencies. Table 3 gives some typical values for a hypothetic chip.

This dependency of chip performance given in time for a complete transaction on available chip current is shown in fig. 10. It can finally be used, to give limits for execution time in the Operating Volume of the Terminal.

TABLE III. OPERATION TIMES DEPENDING ON AVAILABLE CHIP CURRENT FOR HYPOTHETIC CHIP.

Chip current	Fixed Time		Variable Time	
(mA)	memory (ms)	Comm. (ms)	CPU (ms)	Crypto (ms)
8	20	75	230	50
6	20	75	230	50
4	20	75	245	83
3	20	75	361	125
2	20	75	690	249

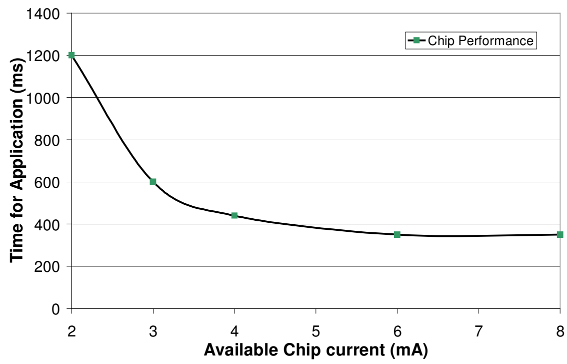

Figure 11. Application time depending on chip current.

VI. CONCLUSIONS

We have presented a concept to calculate the supply power for a contactless 13.56 MHz Transponder chip in the Operating Volume of a Terminal. The concept was applied to the EMVCo / PayPass specifications for Contactless Credit Cards. Using the analytical model of the Biot-Savart law, the H-field distribution over the Terminal loop antenna was calculated as well as driver power, voltage and current. As Credit Cards will require small Transponder antenna areas, we have considered the available chip supply current for different antenna areas in inhomogeneous H-field. Finally, we have given a brief introduction to the chip operation aspects, which relate the available supply power to performance in terms of transaction time for a defined application.

REFERENCES

[1] www.emvco.com/specifications.asp

[2] EMV Contactless Specification for Payment Systems / EMV Contactless Communication Protocol Specification, Version 2.0, Aug. 2007

[3] ISO/IEC JTC1 / SC17 / WG8 N947 R1

[4] ISO/IEC 7811-1:2002

[5] ISO/IEC JTC1 / SC17 / WG8 TF2N553 Measurement methods for antenna classes, June 2007

[6] www.wg8.de