Analysis, Design and Optimization of a Combined Wireless Power Transfer and Near Field Communication System

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***Abstract*—This paper describes how Würth Elektronik eiSos (WE) has developed a combination of wireless power transfer (WPT) and near field communication (NFC) system in a single device. First, this paper describes the general setup of the WPT and NFC system. Constituent parts of the system are analyzed by simulation and verified by measurement. The design of the resonant tank for the wireless power components to achieve high efficiency is described. The methodology for minimum reflectance and impedance matching of the NFC coil to the NFC IC is presented. Finally, some typical applications and the advantages of the system compared to a conventional NFC system are discussed.**

Keywords—wireless power transfer, near field communication, WPT, NFC

I. Introduction

The NFC market is exponentially increasing and is expected to reach 47 billion USD in 2024 [4]. There are now more than 2 billion mobile NFC devices and about 2.1 billion people around the world using NFC mobile payment services.

NFC is a short range, high frequency, low bandwidth wireless communication technology, which enables a standardized communication between two mobile devices like smartphones, smart cards, stickers or tags. NFC uses the same frequency as radio frequency identification (RFID), 13.56 MHz. Although RFID is capable of reception and transmission beyond several meters, NFC is restricted to very close proximity up to 10 cm for data security. The NFC data rate ranges from 106 kbit/s to 848 kbit/s. NFC always involves an 'initiator' like a card reader and a 'target' like a credit card. The initiator actively generates a RF field, which powers the target. [2]

There are three different NFC communication modes. The first two, read/write mode and card emulation mode, use passive communication schemes, where the passive target uses the RF field generated by the initiator. The read/write mode enables reading information stored on NFC tags or smart cards. The card emulation mode provides the opportunity for an NFC enabled mobile device to function as a contactless smart card (e. g. credit card, access card or transportation card).

In this paper, the passive read/write mode and the card emulation mode are used. [3]

The third mode, peer-to-peer, can be used with an active and passive communication scheme. With active communication, the initiator and the target generate their own field. The peer-to-peer mode is used to exchange information such as business card details between two mobile NFC devices, e. g. at smartphones.

In current NFC systems maximum data rates are 848 kbit/s. As the power of the RF field is restricted to 1 W, NFC is mainly used for communication purposes. Conversely, WPT systems can deliver power up to the range of hundreds of Watts or more, but at low in-band data rates, up to some hundred bytes/s.

Now, WE has combined the benefits of high data rates of NFC communication and high power transfer capability, up to 100 W, in a single, small and cost effective WPT/NFC combination device, enabling an efficient solution for commercial and financial transactions and industrial processes.

II. WPT/NFC Combination System

A. Setup of the WPT/NFC System

In this work, a WPT/NFC system has been constructed. For the WPT part, the WE 200 Watt Wireless Power Transfer Development Kit 760308EMP has been used, which is described in a WE application note. [5]

The communication part of the system has been performed with the NXP OM27462CDK NFC development kit. [6]

Fig. 1 shows a simplified block diagram of the setup of the WPT/NFC system. As passive targets, sample NFC cards, which are part of the NFC development kit, have been used.

The cards used in this development stage are initially the NFC tag type 2, in the read/write mode enables a data rate of 106 kbit/s, and secondly the MifareDESFire EV1 card, which enables a maximum data rate of 848 kbit/s and is operated in the card emulation mode. [8]

WE currently offers four different WPT/NFC coils, one as transmitter and three as receivers, as shown in table 1.

TABLE I. WE WPT/NFC COMBINATION COILS

coil	part number	L_1 [μH]	L_2 [μH]	Q_1	Q_2	type
A	760308103305	8.8	1.4	30	47	Rx
B	760308102306	8	1.4	19	47	Rx
C	760308103307	7.8	1.6	19	47	Rx
D	760308101312	24	0.7	125	30	Tx

In table 1, L_1 and Q_1 are the inductance and the quality factor of the WPT part of the coils, measured at 125 kHz, and L_2 and Q_2 are the inductance and quality factor of the NFC part of the coils, measured at 13.56 MHz. Coil D has been used in the WPT/NFC combination system and is shown in fig. 2.

Fig. 2. Coil D.

The NFC part of coil D has been used in the initiator side and the WPT part in the transmitter and receiver sides.

The filter and matching part of the initiator and the resonant tanks of the receiver and transmitter have been determined by calculation, simulation and measurement.

B. Impedance Matching of the NFC coil to the NFC IC

Impedance matching is a very important procedure in RF circuit design to provide the maximum possible energy transfer from a source to its load and to minimize signal reflections back to the source.

In the WPT/NFC combination system, impedance matching is needed to match the differential output impedance of the NFC IC, which is 50 Ω, to the NFC coil impedance.

At the output of the NFC IC, an EMC filter is recommended to filter out the harmonics of the NFC signal and also to contribute to the impedance transformation. The EMC filter is a second order low pass filter and comprises an inductor and a capacitor. The cut off frequency must be higher than the upper sideband frequency determined by the highest data rate (848 kbit/s) in the system. The EMC filter and the matching network must transform the impedance of the NFC coil to 50 Ω.

Fig. 3. shows the complete EMC filter and matching network for the read/write mode, including the equivalent circuit of the NFC coil. The pins Tx1 and Tx2 are the differential transmission output pins of the NFC IC, and TVSS is the ground pin.

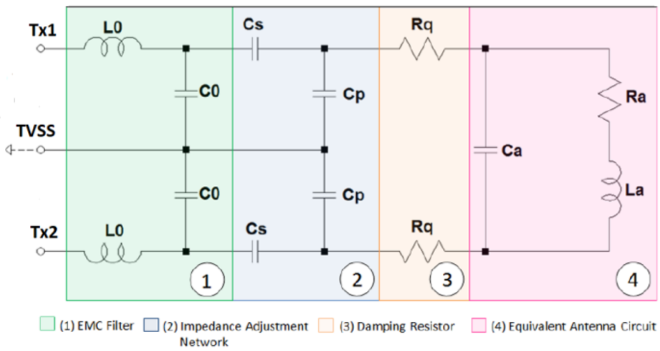

Fig. 3. Standard EMC filter and matching circuit for the read/write mode. [7]

L_0 and C_0 are inductance and capacitance of the EMC filter. C_S and C_P are the matching capacitors, which are placed in L-topology, and R_q is the damping resistor, which reduces the Q factor of the coil. R_a, L_a and C_a are the equivalent coil resistance, inductance and capacitance.

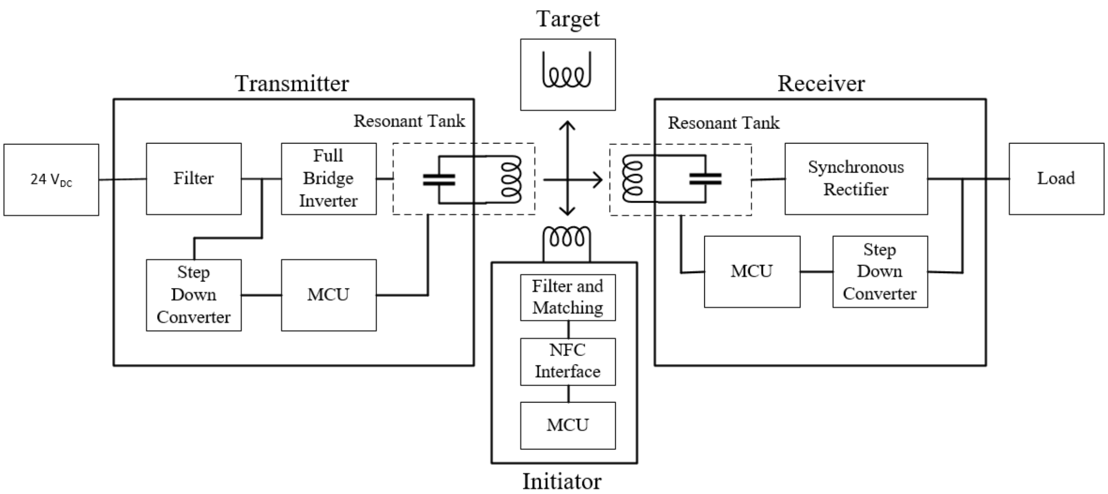

Fig. 1 Simplified block diagram of the WPT/NFC system.

The following design steps have been made to perform the impedance matching:

1. Measurement of the series resistance R_S, parallel resistance R_P, inductance L_a, self resonance frequency f_S of the NFC coil, and determination of the equivalent circuit values of the coil
2. Calculation of the inductance and capacitor values of the EMC filter
3. Determination of the matching circuit components by simulation for the read/write mode
4. Adaption of the matching of the final circuit for the card emulation mode

The right side of fig. 4 shows the series equivalent circuit of a coil.

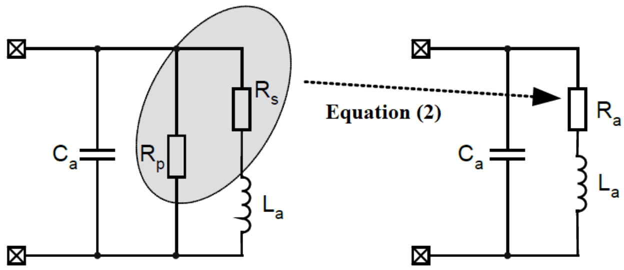

Fig. 4 Series equivalent circuit of a coil. [1]

R_P is the inner parallel resistor of the coil and R_S is the inner series resistance of the coil. L_a is the inductance of the coil and C_a is the parallel equivalent capacitance at the self resonance frequency f_S. R_a is the equivalent series resistor. R_P, R_S and L_a have to be measured at the operating frequency f_{op} = 13.56 MHz. C_a and R_a have to be calculated.

The following values have been measured with a vector network analyzer:

- f_S = 63 MHz
- L_a (13.56 MHz) = 0.7 µH
- R_S (13.56 MHz) = 1.7 Ω
- R_P (13.56 MHz) = 1.9 kΩ

C_a can be calculated with the following formula [1]:

$$C_a = \frac{1}{(2\pi f_S)^2 L_a} = 9.12\ pF \qquad (1)$$

R_a can be calculated with [1]:

$$R_a = R_s + \frac{(2\cdot\pi\cdot f_{OP}\cdot L_a)^2}{R_P} = 3.57\ \Omega \qquad (2)$$

The cut off frequency of the EMC filter f_C can be calculated with equation (3).

$$f_C = \frac{1}{2\pi\sqrt{L_0 C_0}} \qquad (3)$$

Taking the upper side band for the maximum data transfer (13.56 MHz + 848 kHz) into account, the cut off frequency is defined to be 14.8 MHz, which is above the upper sideband frequency of 14.4 MHz.

The filter inductance L_0 = 470 nH has been chosen, which from equation (3) leads to an filter capacitor C_0 = 247 pF.

The capacitors C_S and C_P and the damping resistor R_q have been determined by simulation with the program Advanced Design System (ADS) from Keysight.

The network, shown in fig. 3, has been simulated. Fig. 5 shows the schematic of the simulation.

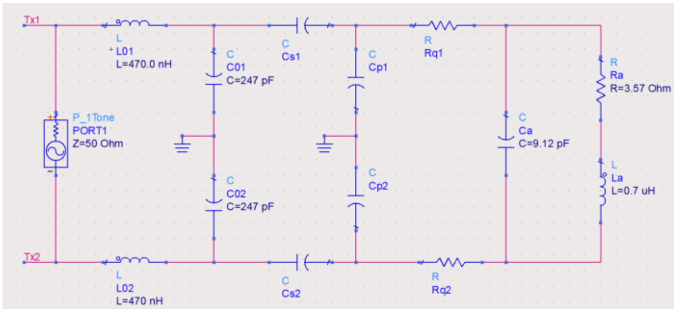

Fig. 5 ADS schematic of the standard EMC filter and matching circuit.

The ADS optimization tool has been used to determine the values for C_S, C_P and R_q.

The simulation results in the following values:

- C_S = 12 nF
- C_P = 284 pF
- R_q = 11 Ω

The components identified by measurement, calculation and simulation have been assembled into the circuit shown in fig. 5.

As the simulation uses ideal lumped elements and the real components have tolerances and losses, values for C_S, C_P and R_q are adjusted to improve matching.

For the card emulation mode, which is needed for a data rate of 848 kbit/s, the circuit shown in fig. 3, has been extended to the circuit shown in fig. 6.

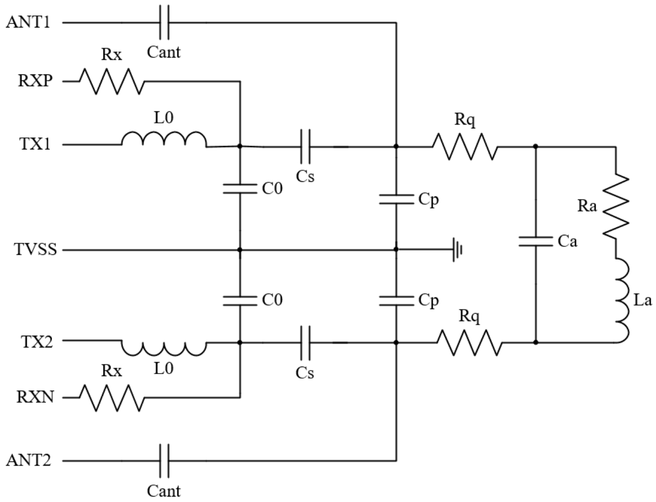

Fig. 6 Extended EMC filter and matching network for card emulation mode.

C_{ant} and R_X have been dimensioned to 82 pF and 4.7 kΩ as recommended in the NFC design kit manual. [6]

C. *Dimensioning of the resonant tanks on the transmitter and receiver side*

To optimize the transmission efficiency of the WPT system, the resonant tanks on the transmitter and receiver have to be dimensioned properly. A resonant tank comprises of the inductance of the coil and a series capacitor. The values of the resonant capacitors have been determined by measurement and calculation. To take the influence of the transmitter coil into account, the inductance of receiver coil L_s' is measured, when the receiver coil is separated from the transmitter coil. The measurements have been performed at a distance of 4 mm. For this distance, the value of L_s' has been measured with an LCR meter as 31.2 µH at a frequency of 100 kHz.

The resonant capacitor C_R, to be integrated at the receiver side, can be calculated using formula (1) and taking L_s' into account in the following way:

$$C_R = \frac{1}{(2\pi f_0)^2 L_s'} = 81\ nF \quad (4)$$

where f_0 is the operating frequency of the power transmission, which is 100 kHz.

The inductance of the transmitter coil L_P is measured at a same receiver to transmitter coil separation as above. The measured value of L_P for that distance is 29.8 µH at a frequency of 100 kHz.

The value of C_T, which is the resonant capacitor of the transmitter side, is calculated similarly:

$$C_T = \frac{1}{(2\pi f_0)^2 L_P} = 85\ nF \quad (5)$$

III. Results

A. *Impedance Matching*

The extended matching network (see fig. 6) has been built up and the simulated and measured values have been used. A higher R_q value of 20 Ω has been utilized to improve the matching.

The reflection coefficient at the input port (between the pins Tx1 and Tx2) has been measured with a vector network analyzer (VNA). Fig. 7 shows the measured reflection coefficient over a frequency range from 12 MHz to 15 MHz, in dB.

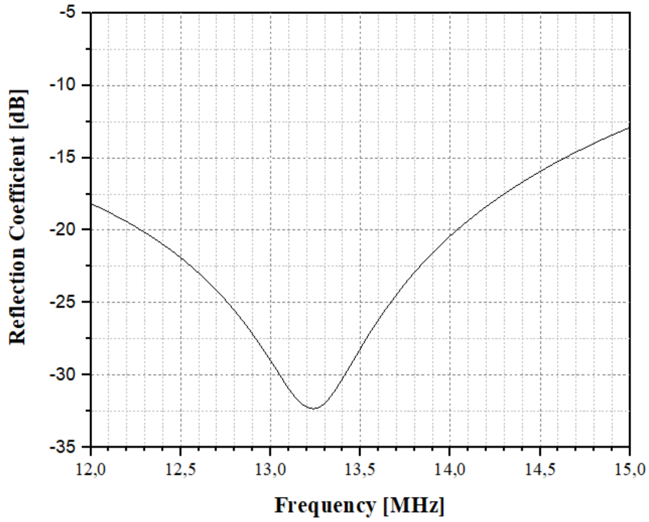

Fig. 7 Measured reflection coefficient over frequency of the extended filter and matching circuit.

It can be seen, that the reflection coefficient at the operating frequency of 13.56 MHz has a value of about -27 dB. This means that about 0.2 % of the incident power is reflected back to the input.

B. *Communication and Power Transfer*

With the standard filter and matching network (see fig. 3) and using the simulated matching values and coil D, communication to the NFC tag type 2 with a data rate of 106 kbit/s could be achieved, up to a separation of 3 cm.

Using the extended filter and matching network (see fig. 6) with a modified damping resistor value of 20 Ω, the data rate capability increased to 848 kbit/s, although the communication separation between initiator and tag (MifareDESFire EV1 card) is reduced to 4 mm.

For the power transmission, the WPT part of coil D has been used on the transmitter and receiver sides.

Using the resonant tank capacitor C_R = 81 nF on the receiver side and C_T = 85 nF on the transmitter side, a DC-to-DC efficiency of about 85 % was reached for a coil separation of 4 mm.

Wireless power transfer of up to 60 W was achieved at standard temperature conditions.

The maximum system efficiency η_{max} of a WPT system can be calculated with equation (6): [9]

$$\eta_{max} = \frac{k^2 Q^2}{(1+\sqrt{1+k^2Q^2})^2} \approx 1 - \frac{2}{kQ} \quad (6)$$

Q is the combined system quality factor of the two individual coils and can be calculated with: [9]

$$Q = \sqrt{Q_1 \cdot Q_2} \quad (7)$$

To calculate the coupling factor k, the following equation has been used:

$$k = \sqrt{1 - \frac{L_P}{L_{leakp}}} \quad (8)$$

L_P is the measured transmitter coil inductance at the defined 4 mm coil separation. L_{leakp} is the stray inductance of the transmitter coil and is measured by shorting the receiver coil at that separation and measuring the inductance of the transmitter coil.

Using the equations (6) - (8), the maximum possible efficiency of the transmitter and receiver combination coils lead to the values in table 2.

TABLE II. WE WPT/NFC COMBINATION COILS COUPLING AND MAXIMUM EFFICIENCY VALUES

Tx coil (see table 1)	**Rx coil (see table 1)**	**k**	**Q**	**η_{max} [%]**
D	A	0.56	61	94
D	B	0.52	48	92
D	C	0.33	48	87

Table 2 shows that the maximum efficiency of the whole WPT system is 94%, achieved with coil A on the receiver side and coil D on the transmitter side. The causes of the losses of the WPT coils are ohmic losses, proximity and skin effects. In addition the losses of the inverter on the transmitter side, and the losses of the synchronous rectifier on the receiver side, have to be taken into account for the overall efficiency of the system.

IV. DISCUSSION

In this paper, a WPT/NFC system has been developed. The dimensioning of the matching and filter network for the NFC part has been described. On the communication part, a data rate of 106 kbit/s up to 3 cm and 848 kbit/s up to 4 mm distance between initiator and target could be realized. For the WPT part, the calculation of the resonant tanks have been performed and the WPT system has been tested. It has achieved an efficiency of 85 % for a transmitter to receiver separation of 4 mm using the WPT part coil D as transmitter and receiver. For the combination of coil D as transmitter and coil A as receiver, a maximum system efficiency of 94 % can be reached.

The next step in the development process would be to manufacture a receiver system, which is able to demodulate the NFC bit stream and visualizes the transmitted message. The NFC part of coils A-C will be used as tags.

Another goal is to demonstrate that the communication and power transmission works at the same time.

An example application of such a WPT/NFC system would be a wireless charging system for mobile devices, enabling payment services.

The advantage of the WPT/NFC system is that the high data rates of a NFC system can be achieved whilst also enabling high wireless power transfer in one small and efficient single device.

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